

AUTO-TECH
MASTERCLASSES



Training for Master Technicians

2018.1

**Injector Testing made
easy with Current Clamps**

**MAF Diagnosis
The Beginning of
Combustion Management**

Air Intake Control Systems

CAN Bus Part 2

**Diagnostics with Fuel Trims
The End of Combustion
Management**

**Alternative Combustion Cycle Engines
Reinventing the Cycle**

**DIESEL & PETROL
ENGINE MANAGEMENT**



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DIESEL & PETROL
ENGINE MANAGEMENT

LOOK FOR THESE SYMBOLS THROUGHOUT THE MANUAL



Note:

Indicates a point of interest



Caution:

Indicates the risk of minor injury, special procedure or possible damage to a component



WARNING:

Indicates the risk of serious or life threatening injury



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with Current Clamps****CONTENTS**

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INTRODUCTION

Fuel injectors work very hard, they are exposed to some of the harshest conditions and yet for the most part they are extremely reliable. But reliability can mean that when a fault occurs they are often not considered as a possible cause.

There are many factors that need to be considered when approaching fuel injector testing:

- Accessibility
- Testing Method
- Diagnostic Time
- Associated Parts
- Injector Cost

There is no doubt an injector tested off the vehicle on a test bench will provide the most accurate overall results for assessing its serviceability. This does not necessarily mean that it is the best method of achieving a diagnosis. Injector removal can be time consuming, will require new seals, will often require other gaskets and parts and may incur a substantial fee if the injector testing is outsourced.

In general, the less intrusive the testing the better the cost outcome for the consumer.



PFI Injector

DPI Injector

CRD Solenoid Injector

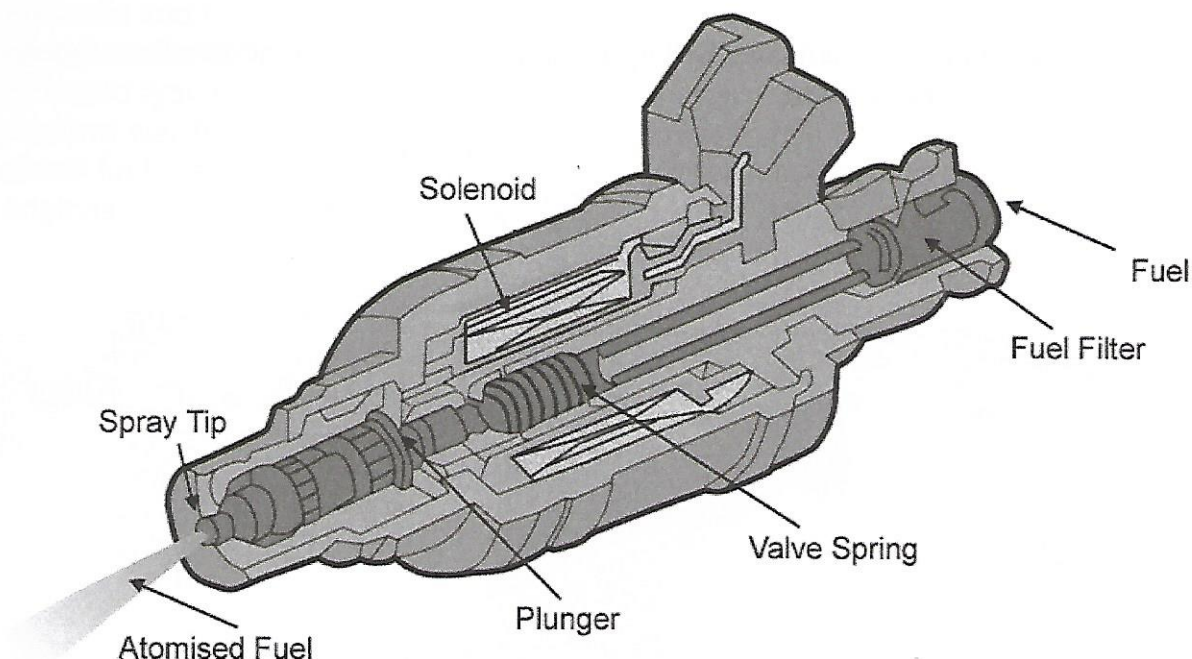
CRD Piezo Injector

INJECTOR TYPES

In this topic we will cover the common types of modern fuel injectors. This means we will not cover some of the older types such as Throttle Body Injectors, Diesel Unit Injectors, Mechanical Diesel Injectors and after market modified components.

Port Fuel Injectors

Port Fuel Injectors are fitted to most modern petrol driven vehicles. They are positioned just behind the Intake Valves and injection begins just prior to the opening of the intake valves.



These fuel injectors are among the most reliable, mainly due to their removal from the combustion chamber. They are less efficient because some of the fuel condenses on the walls of the intake manifold and intake ports of the cylinder head. This process provides a vital cleaning process, helping to keep the backs of the intake valves clean of deposits.

INJECTOR TYPES continued...

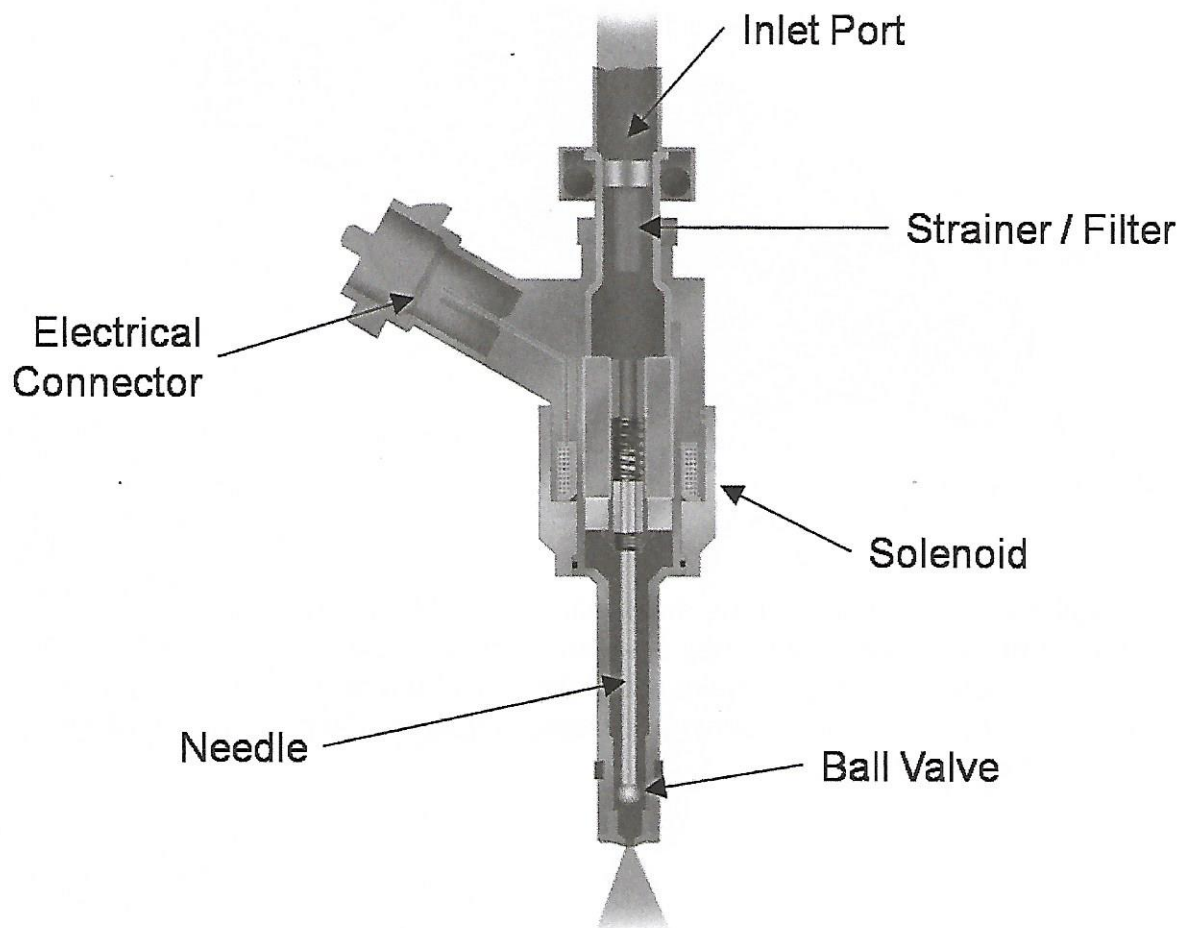
Direct Petrol Injectors

This system is far more detrimental to NOx due to lack of swirl + carbon build up.

While the principle design of the DPI Fuel Injector is not unlike that of a Port Fuel Injected engine, the environment and conditions under which it operates are somewhat different.

A key attribute that improves the performance of DPI Fuel Injectors is the high pressure fuel supply. With the assistance of a high voltage injector trigger the injectors produce a finely atomised and precise charge of fuel directly into the combustion chamber.

Owing to these improvements the DPI Fuel Injector is noticeably noisier than those of a Port Fuel Injected system.



Note:

It is becoming a well known concern amongst many DPI vehicles that carbon build up in the intake manifold and cylinder head can clog and restrict intake flow. This is being addressed in many of the latest model engines by using dual injection, where both PFI & DPI Injectors are used on a single vehicle!

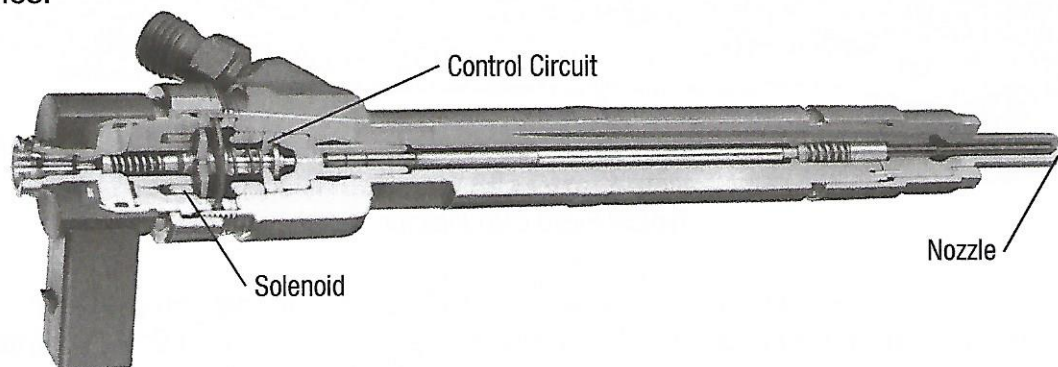
INJECTOR TYPES continued...

Common Rail Diesel Injectors

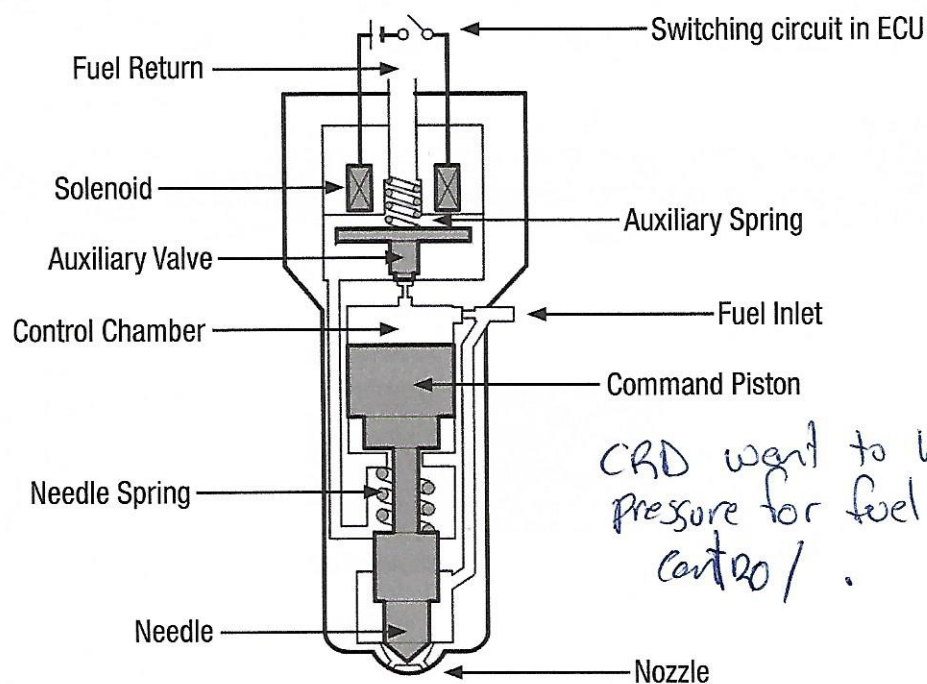
Common Rail Diesel Injectors can be actuated with either an Electro-solenoid or a Piezoelectric. It is also important to understand that due to the extremely high operating pressures, CRD Injectors are indirectly actuated.

Electro-solenoid

Electro-solenoid diesel fuel injectors were the typical fitment for CRD systems that were built to run at EURO III. In European countries and US CARB states Piezoelectric Injectors were popular from EURO IV (or US equivalent) onwards. For Australia and New Zealand solenoid technology improved and often by the time the emission standard was introduced here the significantly cheaper and more reliable Solenoid type injectors were capable of meeting our needs. These injectors now perform well for up to 5 injections per cycle. Beyond this rate the Electro-solenoid diesel fuel injectors struggle to meet the operational demands of the highly efficient engines.



Typical Solenoid type CRD Injector



CRD went to very high pressure for fuel quantity & control.

Schematic diagram of Solenoid type CRD Injector

INJECTOR TYPES continued...

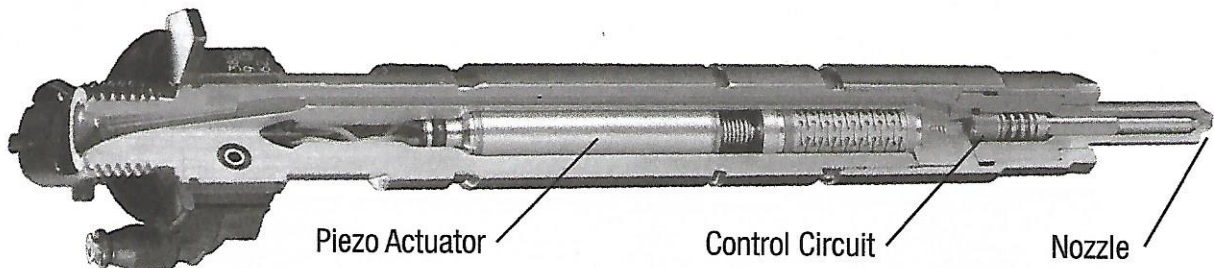
Piezoelectric

Piezoelectric diesel fuel injectors utilise a pack (approximately 400 discs) of Piezo Crystals. The nozzle design of a Piezo Electric is of the same principle design as Electro Solenoid diesel fuel injectors.

When excited by an electrical pulse from the Engine Control Module (ECM) the individual piezo discs expand, collectively this creates enough deflection to actuate the auxiliary valve and trigger the fuel injection.

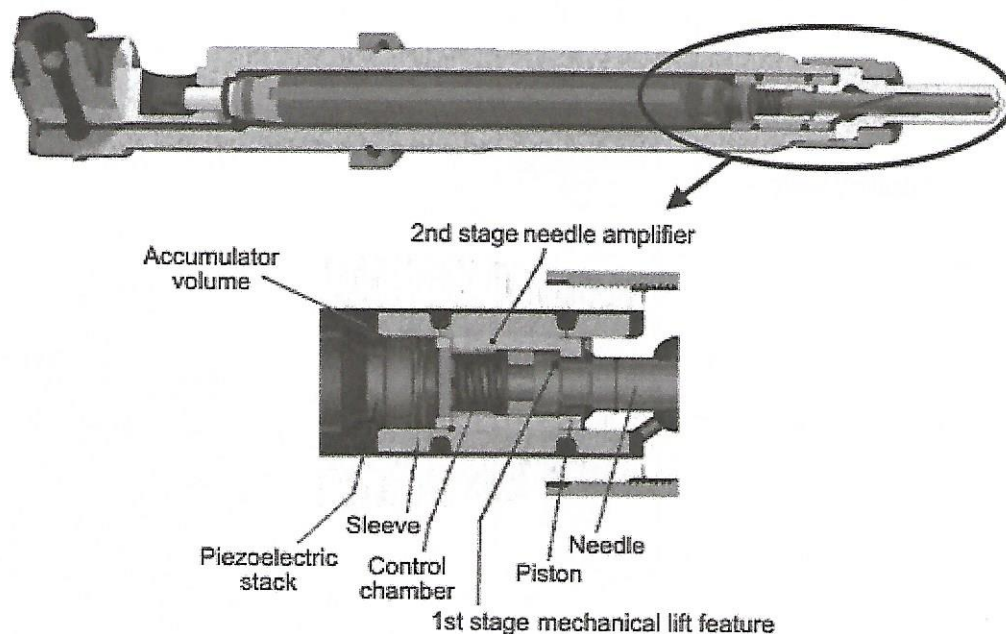
The benefits of Piezoelectric over Electro Solenoid diesel fuel injectors include:

- Used for up to 7 injection per cycle
- 75% less moving mass than electro solenoid type.
- Faster response = more efficient and cleaner running
- More precise fuel metering



Typical Piezo CRD Injector

In 2009 Delphi released a direct acting piezo CRD injector, it was adopted by Mercedes Benz on a variety of 2009MY CRD models with 1.8L and 2.1L engines. It was plagued by issues and eventually replaced by a traditional in-direct type injector. Fortunately, these injectors were only used on tightest emission specs (EURO V) and very few found their way into the Australian and New Zealand markets which was adhering to the EURO IV spec at the time.

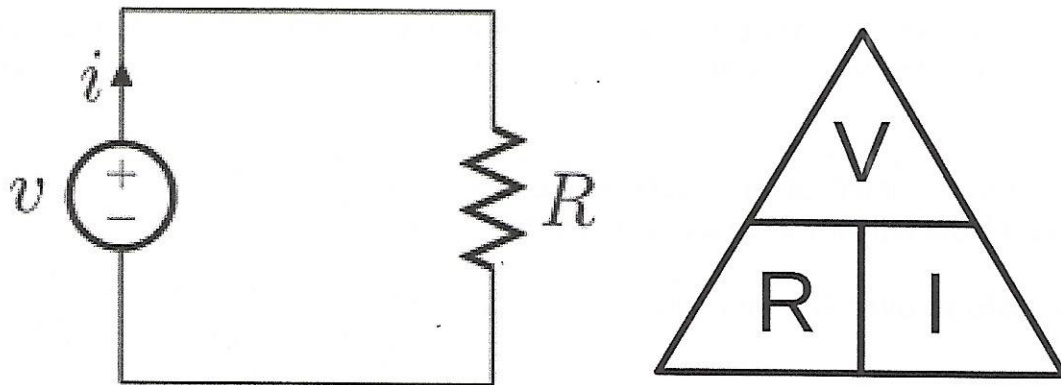


Delphi Direct Acting CRD Injector

TESTING

So why is current so important in Fuel Injector testing?

When we look at the voltage we see the command signal that has been sent by the Engine ECU, if we look at the current draw we see a combination of the signal sent by the Engine ECU mixed in with results of how the individual injectors have reacted to that signal. This makes current a very useful diagnostic value.



Current (i) is the rate at which a charge passes by a point in a circuit and its relationship to Voltage (v) and Resistance (R) as explained by Ohms Law.

Don't ignore the voltage

Having stated the importance of current testing this does not mean the voltage values should be ignored. It only takes a few extra seconds to connect a voltage probe at the same time as the current clamp.

Back Leakage - CRD

On common rail diesel engines it is also important to check the back leakage quantities. Because virtually all CRD engines use in-direct acting injectors the current test is only indicative of the injectors actuator (solenoid or piezoelectric) and the control circuit. Back Leakage provides feedback on the mechanical condition of the injector.

Voltage Drops in +4 - feeds of Injectors changes the opening timing (lengthens)

UNDERSTANDING THE WAVEFORMS

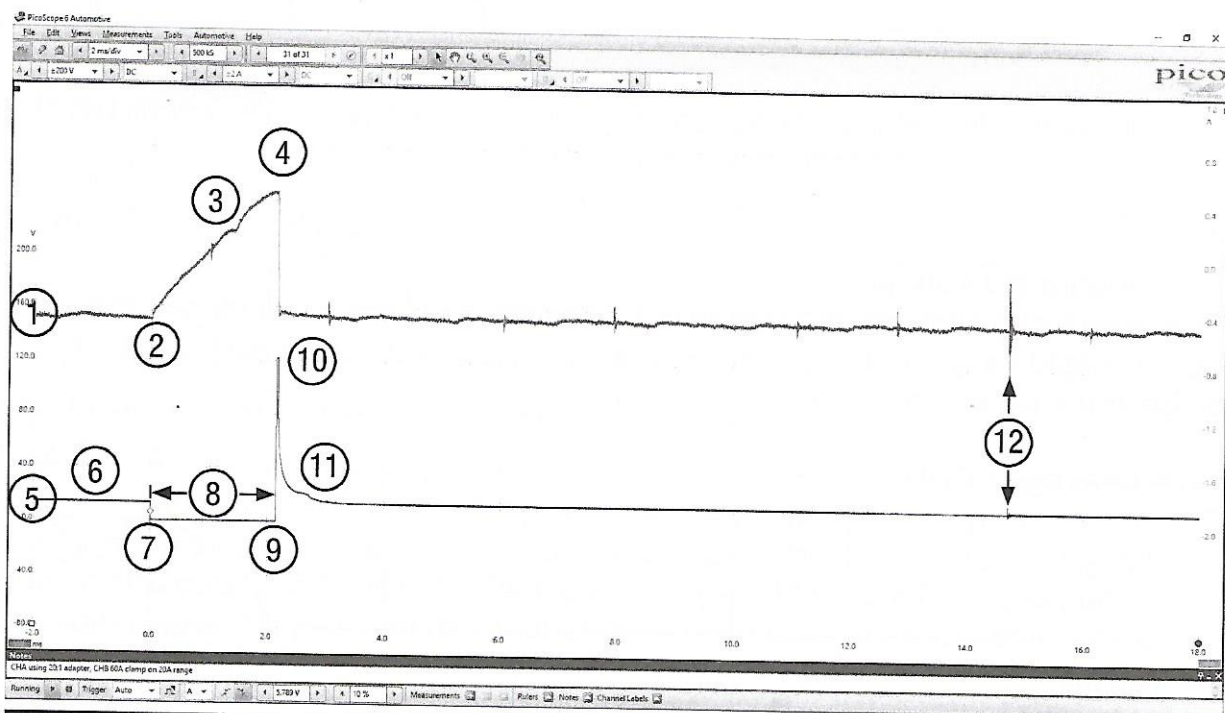
Port Fuel Injection - Voltage vs. Current

All modern PFI systems operate on a sequential injection system. The Injection timing is provided by the primary ignition signal and if built after 2005 (EURO III) will include misfire detection that will cut the fuel to a cylinder that has identified a misfire to prevent damage to the three way catalyst.

PFI systems use a battery volts power supply that usually feeds all of the injectors, if the engine has two banks (eg. V6 or V8) there may be separate power supplies to each bank. The injectors are actuated by completing the circuit to ground in the ECU.

This type of fuel injection is usually referred to as saturation control, in contrast to Peak and Hold which will be explained in the DPI section of this topic.

PFI waveform over 20 milliseconds - Injection Event



PFI - Voltage vs. Current waveform

1	Current Waveform	2	Current Ramp
3	Pintle Hump - Opening	4	Peak Current
5	Voltage Waveform	6	Feed Voltage
7	Transistor ON	8	On-time ($\approx 2.2\text{ms}$)
9	Transistor OFF	10	Peak Voltage
11	Pintle Hump - Closing	12	Feedback

UNDERSTANDING THE WAVEFORMS continued...

1: Current Waveform

Achieved by placing a current clamp on either of the injector wires. A typical amperage scale of ± 2 Amps is usually sufficient.

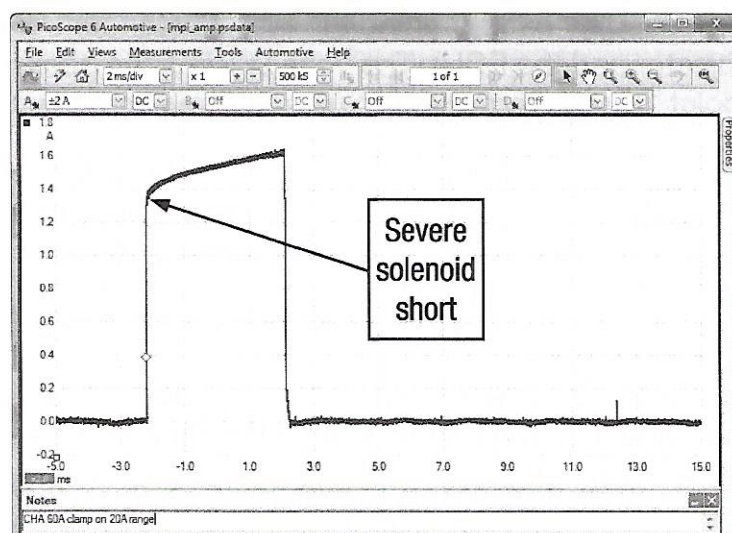
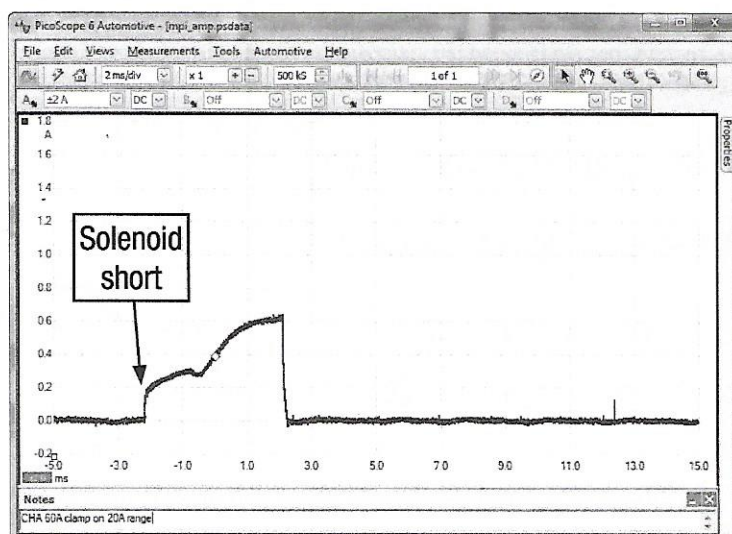
2: Current Ramp

Should be a consistent arc (with the exception of the Pintle Pump).



Note:

A vertical start to the arc is usually an indication of a faulty solenoid winding. If this occurs, compare against the other injectors!



3: Pintle Hump - Opening

There used to be a rule that suggested that the Pintle Hump in the current waveform should be at approximately 60% of the on-time. This rule is no longer relevant and they can be found anywhere in the current ramp. The best method for checking the position of the Pintle Hump is to compare it to the other cylinders.

UNDERSTANDING THE WAVEFORMS continued...

4: Peak Current

The Peak Current is often around the 1 Amp value.



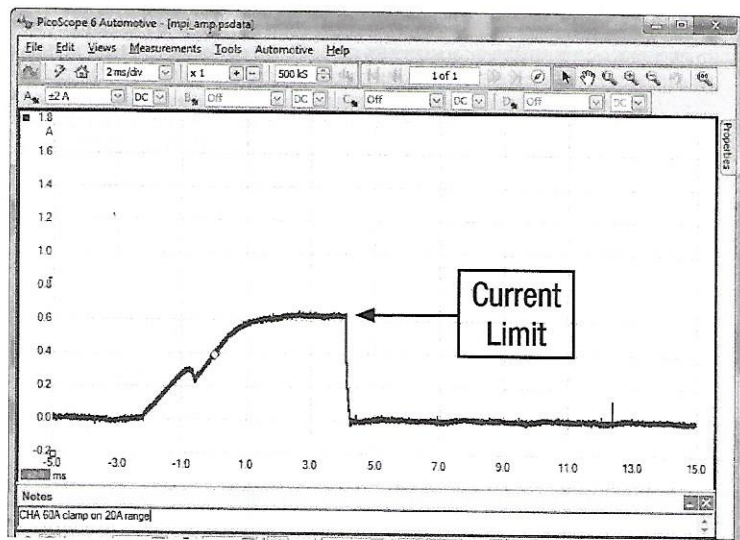
Note:

If the current ramp levels off at the top as it approaches the off trigger it usually indicates that there is a current limiting circuit within the ECU. This is normal!

Pattern will revert

① Back to a STD Pattern while you increase RPM. (Turn off Zener Diode).

② Car Manufacturers are clipping amps & storing this energy.



5: Voltage Waveform

Achieved by back-probing the fuel injector control wire (the wire between the injector and the ECU). The voltage will often peak well over the 100V mark (see point 10), so start with a ± 200 Volt scale and adjust as required.



Caution:

An attenuator may need to be connected into the scope lead to prevent the voltage spike from damaging the Oscilloscope!

6: Feed Voltage

Because no current flows when the injector is turned off the full feed voltage should be evident on the control side of the injector. This should be near battery volts (12.6 to 14.5 Volts depending on the charging system type).

7: Transistor ON

When the ECU turns the transistor ON, the voltage should drop towards ground. When the injector circuit is switched to ground the current will start to flow, the ground voltage will vary depending on whether the ECU uses a Bipolar Junction Transistor (BJT) or a Metal Oxide Semiconductor Field-Effect Transistor (MOSFET). Because of the difference in resistance across the transistor gate and the varying current flow a BJT should have an on-time voltage of 0.7 to 1.0 Volts while a MOSFET should have an on-time voltage of 0.2 to 0.3 Volts.

UNDERSTANDING THE WAVEFORMS continued...

8: On-time

The on-time is determined by the ECU and is directly related to fuel injection quantity. The longer the on-time the greater the fuel injection quantity. On-time is also used to compensate for low battery voltage, during engine cranking or if a charging system fault is detected the ECU will increase on-time to compensate for reduced fuel pressure from the fuel pump as well as the weaker magnetic field created by the injector solenoids.

9: Transistor OFF

The ECU will end the injection event by switching off the transistor. This causes the magnetic field in the injector solenoid to collapse inducing a voltage spike.

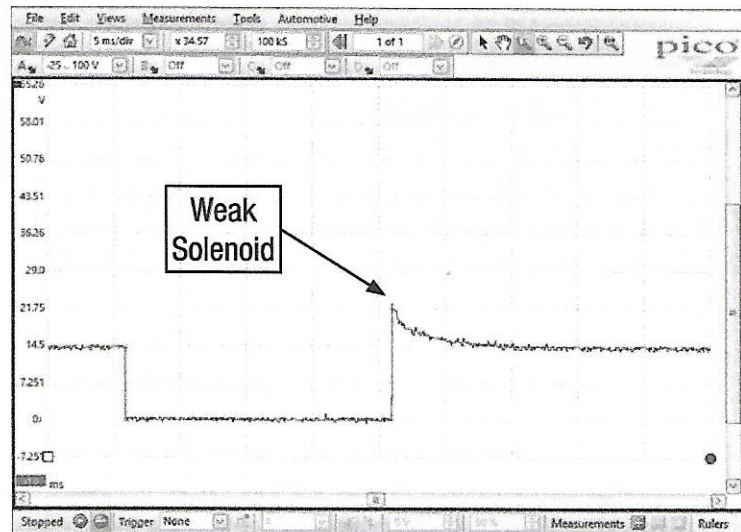
10: Peak Voltage

This voltage spike should be in excess of 60 Volts (most commonly 100-150 Volts) but should also be similar to the spike created by the other injectors.



Note:

The height of the voltage spike is indicative of the solenoid strength!

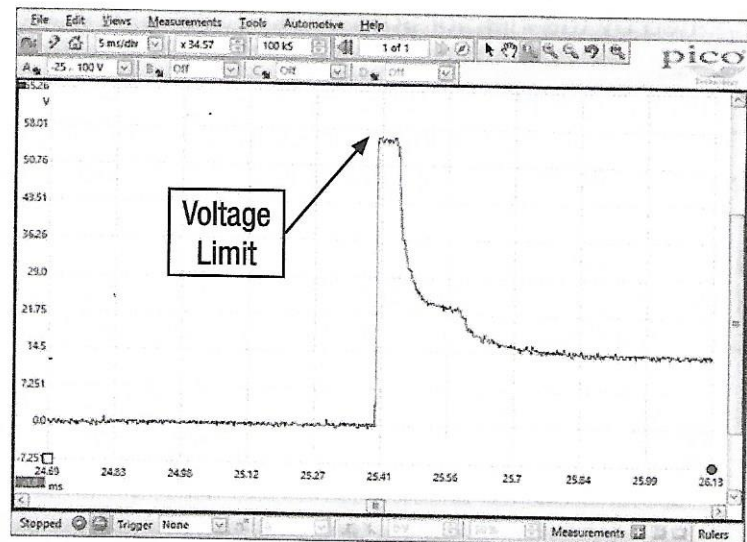


UNDERSTANDING THE WAVEFORMS continued...



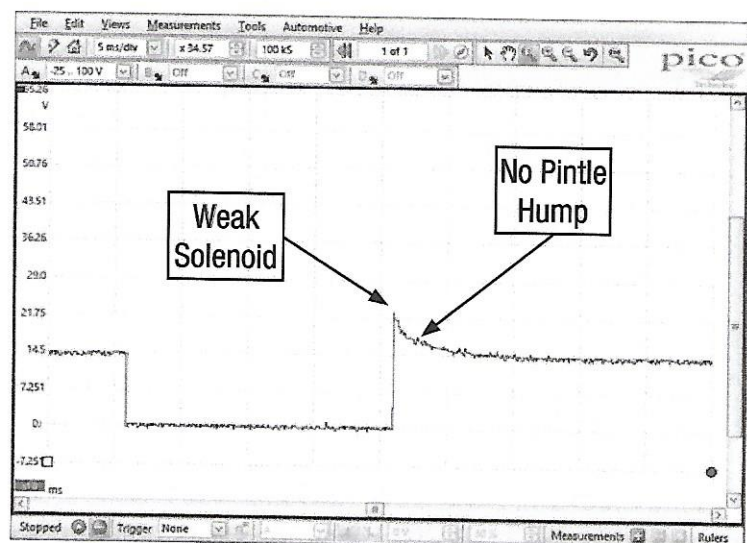
Note:

An exception to this are ECU's that include a voltage limiting diode, which dump excess voltage above their preset value to ground. A Diode limited system can be easily identified by the cut off voltage spike!



11: Pintle Hump - Closing

The Pintle Hump in the Voltage waveform is the result of the injectors armature moving back through the solenoid windings, temporarily turning it into a generator. The generated voltage creates the Pintle Hump. The best method for evaluating the position of the Pintle Hump is to compare it to the other cylinders.



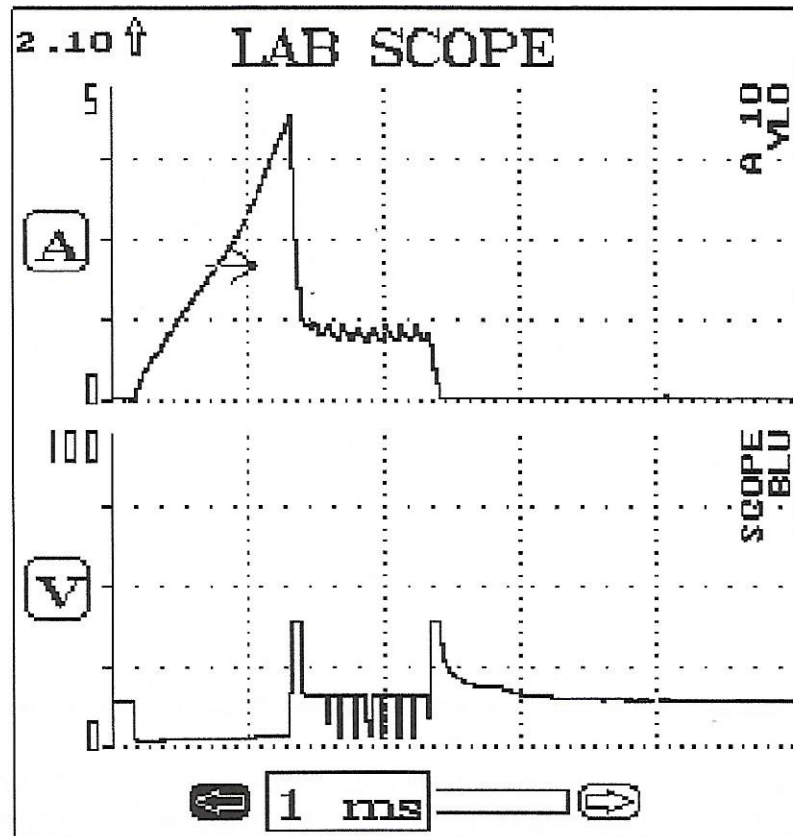
12: Feedback from other components

These imperfections in the waveform are due to the voltage spikes generated by other injectors and in some cases by the ignition coils ricocheting back through other circuits. These are completely normal and do not affect the ECU's control over the fuel injector.

UNDERSTANDING THE WAVEFORMS continued...

Direct Petrol Injection - Voltage vs. Current

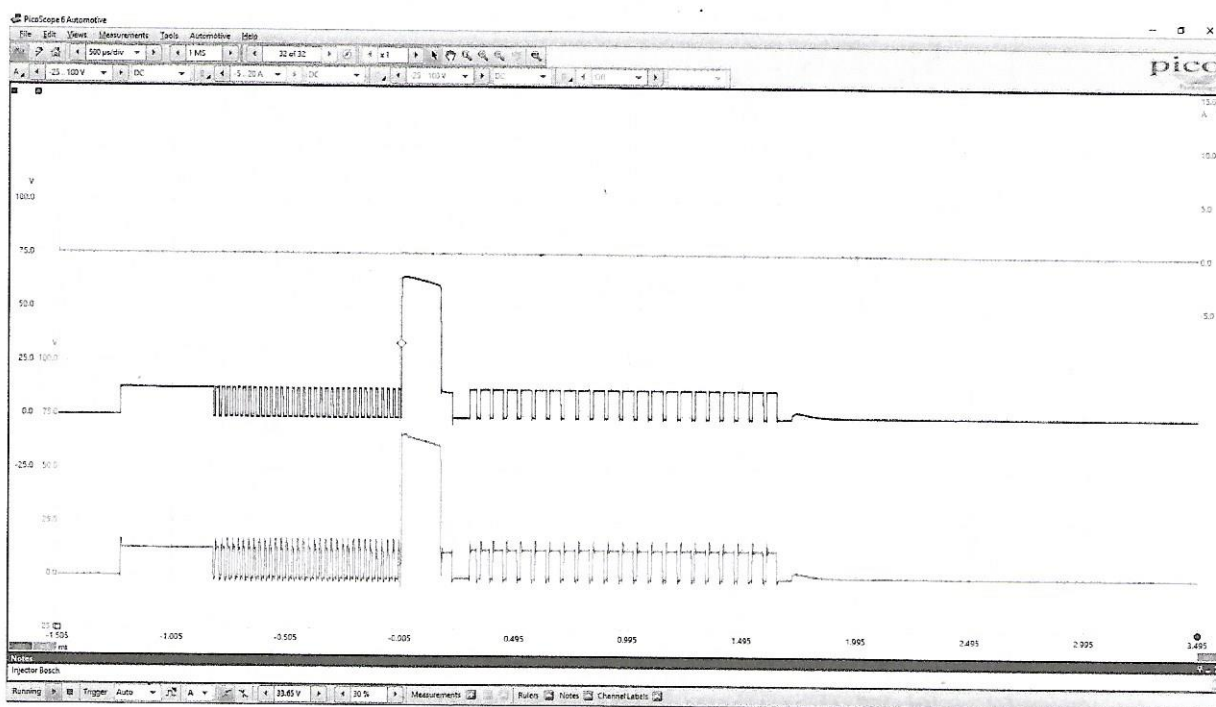
During the mid 1980's as carburettors were being phased out the simplest form of fuel injection was Throttle Body Injection (TBI). TBI used low impedance (resistance) injectors and they were controlled by a method called Peak and Hold (also used in some aftermarket high performance engine control systems).



TBI injection waveform showing a ground side switched configuration while employing a duty cycle hold. The injectors are powered via a relay (Battery Volts) and the ECU only controls the ground side of the injector. The 40 Volt (Voltage Limited) spikes are produced by the collapse of the magnetic field in the injector solenoid.

UNDERSTANDING THE WAVEFORMS continued...

Direct Petrol Injection (DPI) uses a form of Peak and Hold control with a duty-cycle to control current flow during the hold period. Manufacturers don't refer to it as Peak and Hold, but a comparison of the waveforms proves the point. A variation in the circuit design of DPI compared to PFI or TBI is the ECU's control over both sides of the fuel injectors solenoid (this is also a feature of CRD). This change in design is the single largest cause of confusion for technicians. Seeing two identical but varying waveforms coming from each terminal of the fuel injector leaves many wondering what is actually going on.



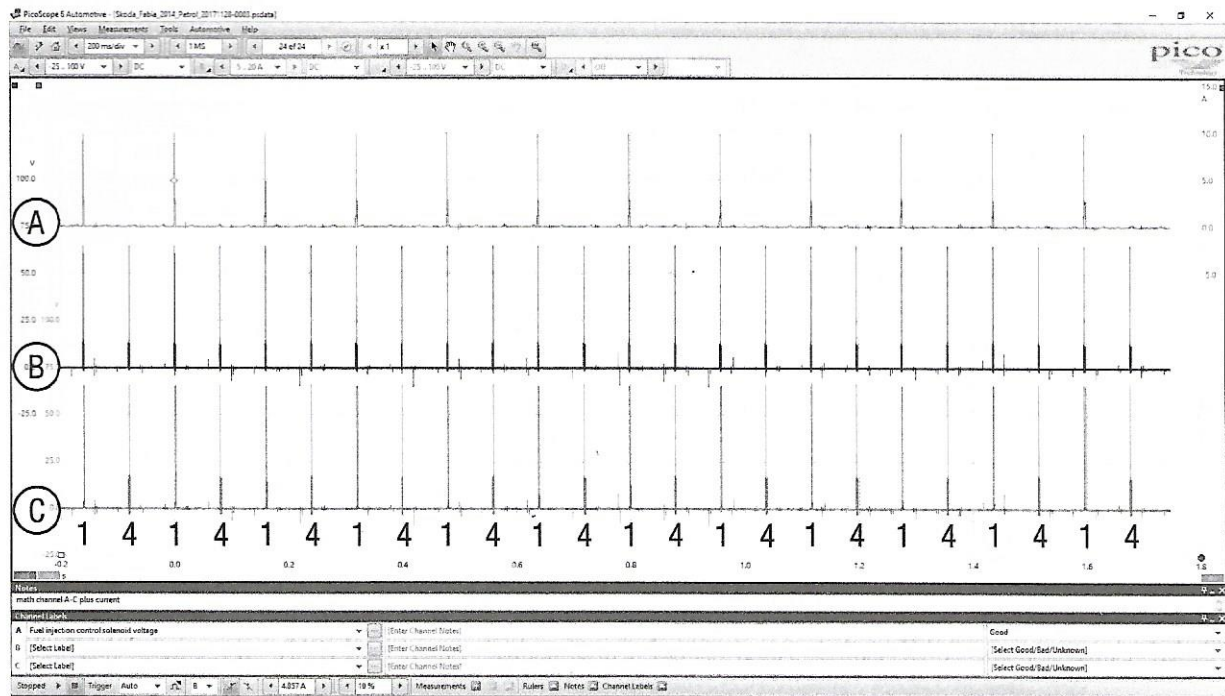
The bottom two traces of this waveform show the voltages measured across the two terminals of a DFI Injector on a VW TSI engine. The breakdown of the operation over the following pages will explain how such waveforms are possible.

Manufacturers keep their engineering information mainly to themselves for the most part, this is partly for competitive reasons (patents etc...) and partly for the reason that they see no need in providing this information to their dealer technicians. If an issue arises it is cheaper for a manufacturer to fix the vehicle with parts than diagnose with labour. This approach does not usually work so well for the independent workshop.

The main reason for switching both sides of a fuel injector is that it allows multiple injectors (usually grouped into banks of two opposing cylinders) to share a single High Voltage DC/DC Converter (Boost Capacitor) that provides the high voltage required to open the injector. Another theory is that it also allows the high voltage spikes created by the closing of the injectors to be harnessed to recharge the High Voltage DC/DC Converter. The High Voltage DC/DC Converter is integrated into the Engine ECU or can be found in the Injector Driver Module (where fitted).

UNDERSTANDING THE WAVEFORMS continued...

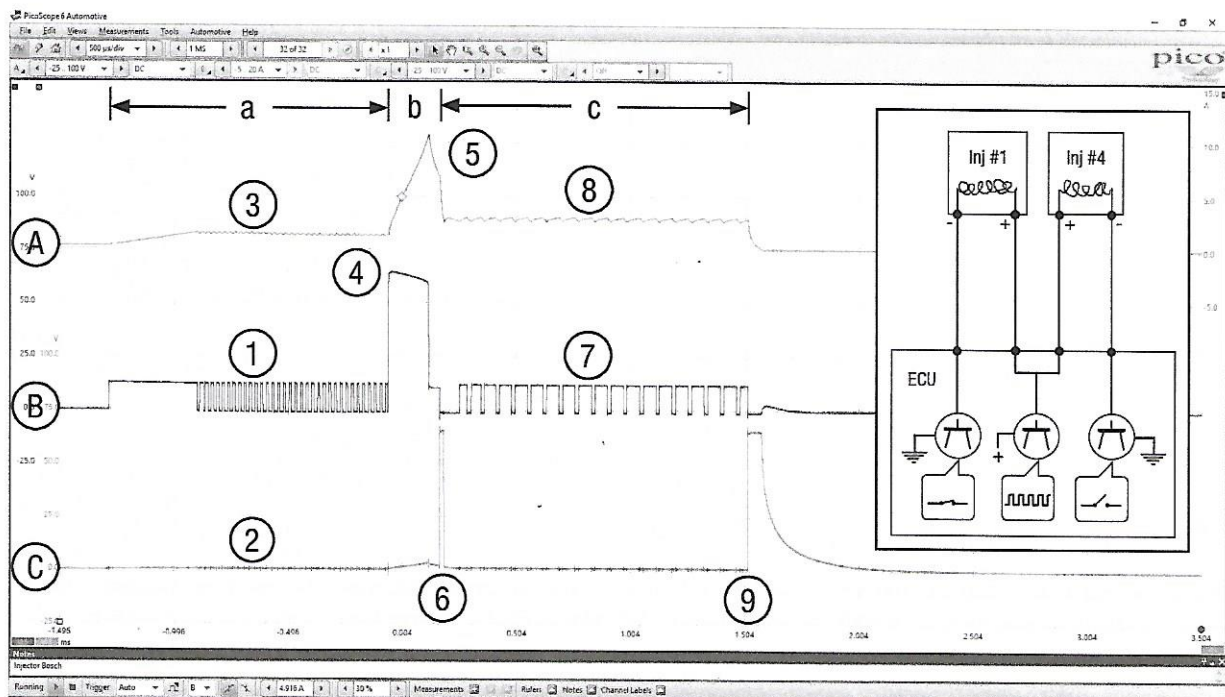
DPI waveform over 2 seconds



This waveform shows the relationship between the injector control of cylinders #1 and #4. The bottom two traces are voltage at both sides of injector #1 and at this time frame it is not possible to see the differences. The top trace is current flow at injector #1 and clearly shows that while there are voltage signals present there is no current flow at every second cycle. No current flow means that the injector is not responding to the voltage signals. This is explained in more detail in the following two waveforms.

UNDERSTANDING THE WAVEFORMS continued...

DPI waveform over 5 milliseconds - Injection Event



DPI - Voltage vs. Current waveform - Injection Event

A	Current trace	B	Voltage trace (+V)
C	Voltage trace (-V)	a	Charge HV DC/DC Converter period ($\approx 1.3\text{ms}$)
b	Peak period ($\approx 0.2\text{ms}$)	c	Hold period ($\approx 1.3\text{ms}$)
1	Duty Cycle (Battery Volts)	2	Ground ($\approx 0\text{ Volts}$)
3	Charge Current ($\approx 2\text{ Amps}$)	4	Peak Voltage ($\approx 65\text{ Volts}$)
5	Peak Current ($\approx 11\text{ Amps}$)	6	Small Voltage Spike (Limited to 65 Volts)
7	Hold Duty Cycle (Battery Volts)	8	Hold Current ($\approx 3.5\text{ Amps}$)
9	Large Voltage Spike (Limited to 65 Volts)		

The injection event can be broken into 3 periods, Booster charging, Peak and Hold.

Charging period

The Duty Cycle On-time is directly proportional to the current draw, during the charging period (a) the -V side of the injector is switched to ground (2), a duty cycle on-time of $\approx 50\%$ is applied to the +V side of the injector (1) creating a current draw (3) that is insufficient to open the injector. These voltage pulses cause the magnetic field in the injector to build and collapse, the voltage spikes are stored in a capacitor.

Peak period

The High Voltage DC/DC Converter uses the voltage (4) stored in the capacitor to create enough current flow (5) to open the fuel injector. Once the injector is opened the voltage drops from $\approx 65\text{ Volts}$ to a 12 Volts duty cycle, the partial collapse of the magnetic field strength and Back EMF is induced into the -V circuit (6).

UNDERSTANDING THE WAVEFORMS continued...

Hold period

During the hold period the duty cycle on-time of $\approx 75\%$ (7) allows enough current (8) to keep the pintle open. When the injection cycle ends the magnetic field collapses completely inducing another back EMF into the $-V$ circuit (9). After the completion of the Injection event the ground is removed from the $-V$ circuit.



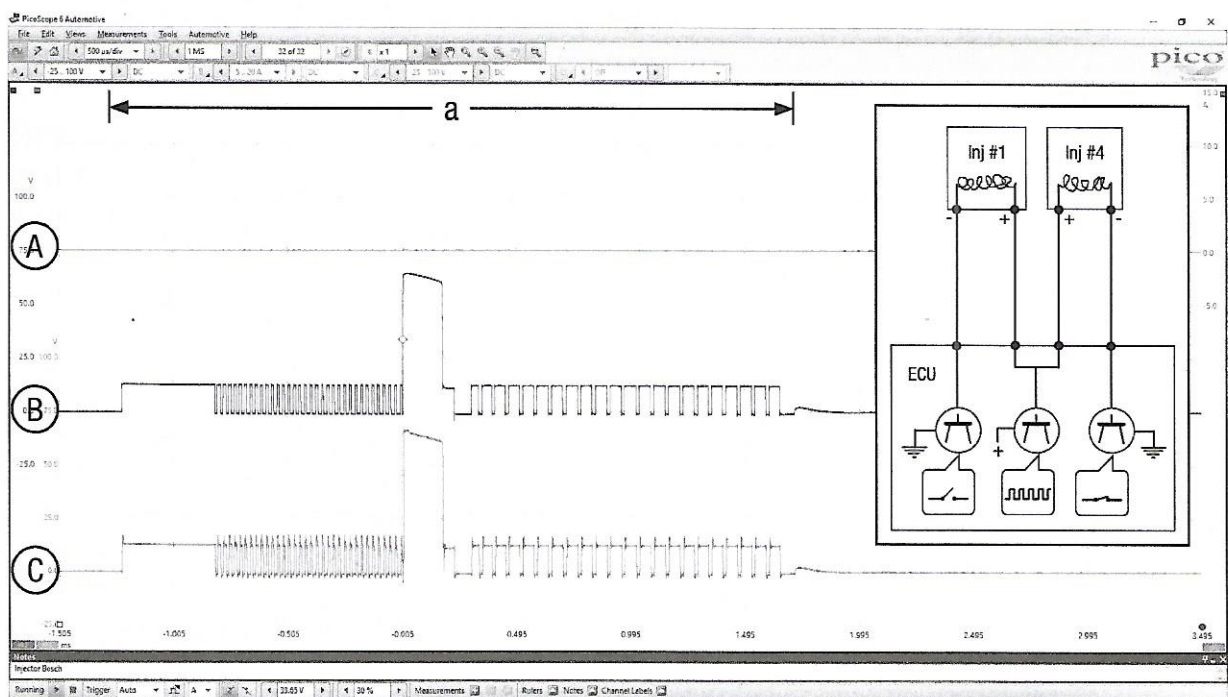
Note:

The charging circuit for the High Voltage DC/DC Converter is not always charged via the injector.

The voltages in these examples were taken from a VW TSI, other vehicles may use anywhere from 40-90 Volts to open the injector!

Current draw will vary with voltage and resistance of the solenoid!

DPI waveform over 5 milliseconds - Opposing Injection Event



DPI - Voltage vs. Current waveform - Opposing Injection Event

A	Current trace	B	Voltage trace (+V)
C	Voltage trace (-V)	a	360° Crank rotation (opposing cylinder) period

When the crankshaft has turned 360° the opposing cylinder is on the firing cycle. The ECU control leaves the Low Side Transistor open. Because the solenoid coil is simply a resistor, a resistor without current flow will display the same voltage on both sides. Therefore the +V (B) and -V (C) traces are virtually identical. These voltages confuse many technicians, however the proof lies in the current flow and it can be clearly seen on the current trace (A) that no current is flowing.

UNDERSTANDING THE WAVEFORMS continued...

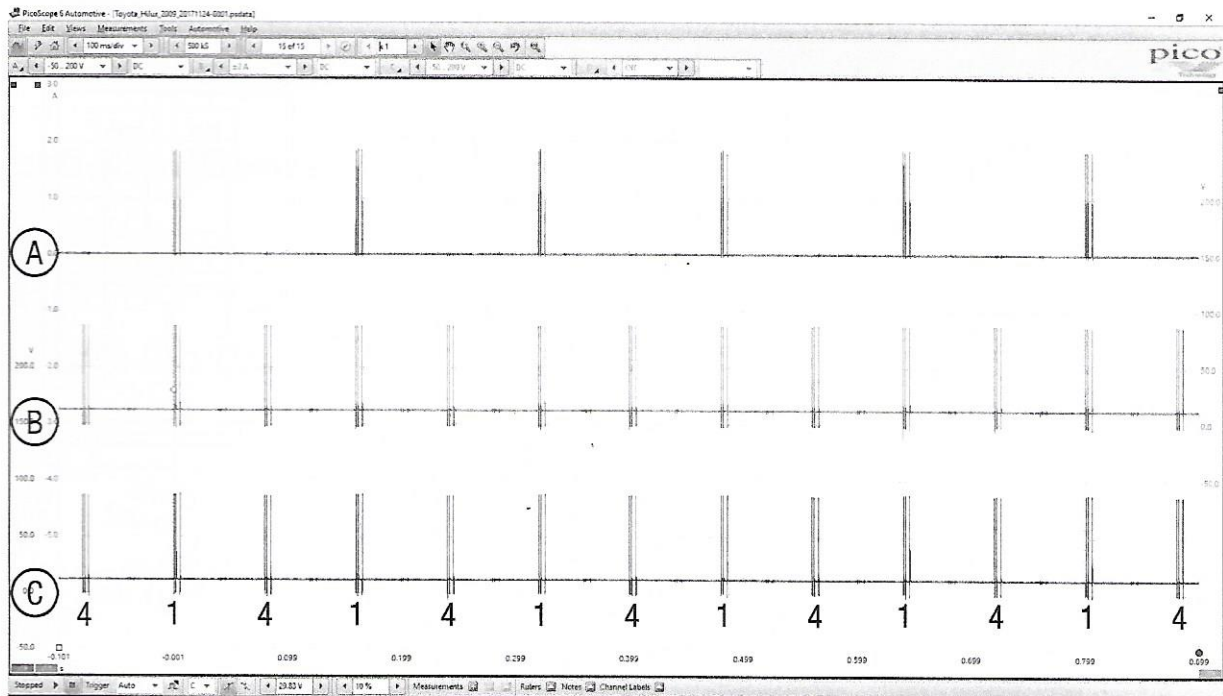
CRD Solenoid Injection - Voltage vs. Current

Common Rail Diesels (CRD) with solenoid injectors use a form of Peak and Hold control with a duty-cycle to control current flow during the hold period, that is very similar to the control used in most DPI systems. As with DPI, manufacturers don't refer to it as Peak and Hold, but a comparison of the waveforms (shown in the DPI topic) proves the point.

Again, as with the DPI systems, the main reason for switching both sides of a fuel injector is that it allows multiple injectors (usually grouped into banks of two opposing cylinders) to share a single High Voltage DC/DC Converter (Boost Capacitor) that provides the high voltage required to open the injector. Another theory is that it also allows the high voltage spikes created by the closing of the injectors to be harnessed to recharge the High Voltage DC/DC Converter. The High Voltage DC/DC Converter is integrated into the Engine ECU or can be found in the Injector Driver Module (where fitted).

UNDERSTANDING THE WAVEFORMS continued...

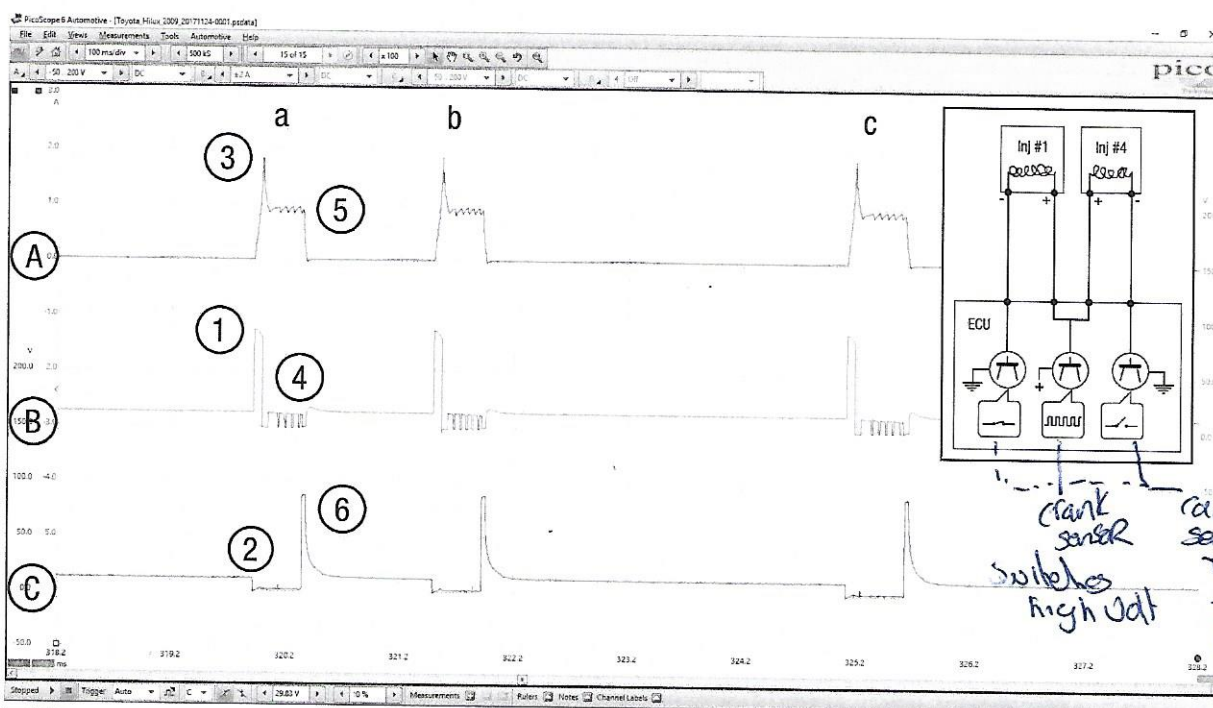
CRD Solenoid waveform over 1 second



This waveform shows the relationship between the injector control of cylinders #1 and #4. The bottom two traces are voltage at both sides of injector #1 and at this time frame it is not possible to see the differences. The top trace is current flow at injector #1 and clearly shows that while there are voltage signals present there is no current flow at every second cycle. No current flow means that the injector is not responding to the voltage signals. This is explained in more detail in the following two waveforms.

UNDERSTANDING THE WAVEFORMS continued...

CRD Solenoid waveform over 10 milliseconds - Injection Event



CRD Solenoid - Voltage vs. Current waveform - Injection Event (x3)

A	Current trace	B	Voltage trace (+V)
C	Voltage trace (-V)	a	Pre-injection event #1 ($\approx 0.4\text{ms}$)
b	Pre-injection event #2 ($\approx 0.4\text{ms}$)	c	Main Injection event ($\approx 0.6\text{ms}$)
1	Peak Voltage ($\approx 85\text{ Volts}$)	2	-V Grounded ($\approx 0\text{ Volts}$)
3	Peak Current ($\approx 1.9\text{ Amps}$)	4	Hold Duty Cycle (Battery Volts)
5	Hold Current ($\approx 0.9\text{ Amps}$)	6	Back EMF (Limited to 85 Volts)

Unlike DPI which will only do multiple injections under certain circumstances, CRD uses multiple injections under almost all circumstances. This example shows two pre-injections and a main injection event. It is also worth noting that in this example there is a constant Battery Volts supply to the +V side of the injector, it is believed that this is used to energise the High Voltage DC/DC Converter to create the 85 Volts required to open the injectors. Each injection event can be broken into two periods, Peak and Hold.

Peak period

The High Voltage DC/DC Converter uses the voltage stored in the capacitor (1) to create enough current flow (3) to open the fuel injector. Once the injector is opened the voltage drops from $\approx 85\text{ Volts}$ to a 12 Volts duty cycle.

Hold period

During the hold period the a duty cycle on-time of $\approx 75\%$ (4) allows enough current (5) to keep the pintle open. When the injection cycle ends the ground is removed from the -V circuit (C) and magnetic field collapses completely inducing a back EMF into the -V circuit (9).

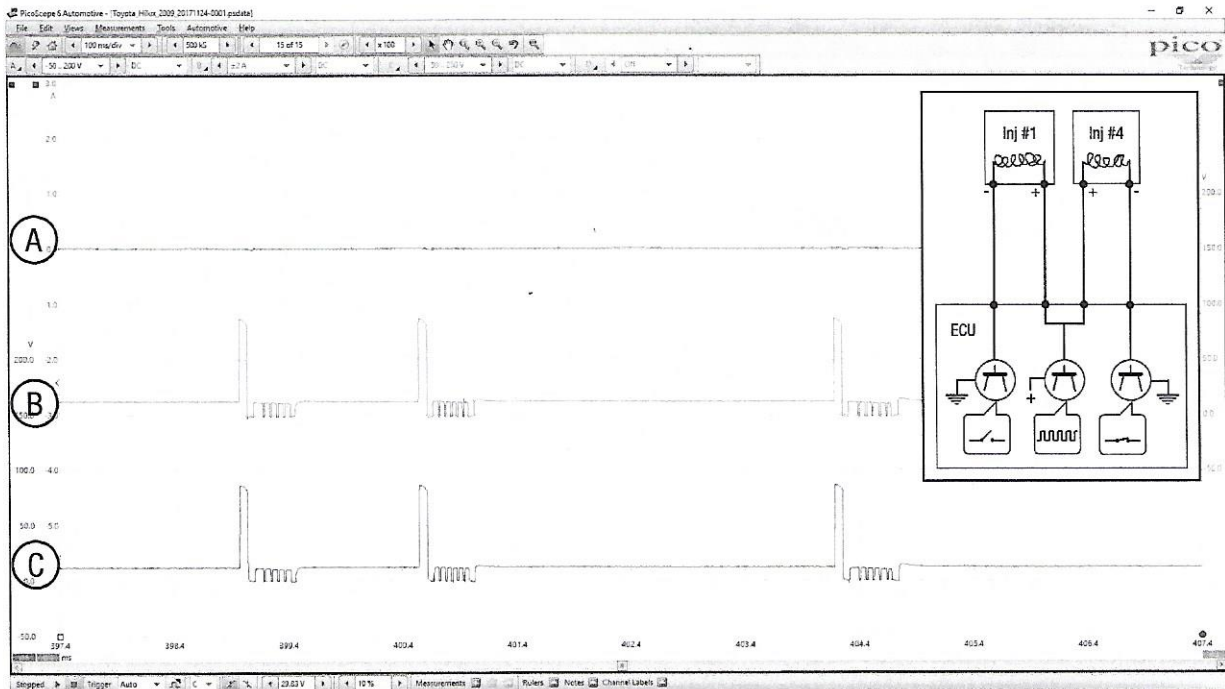
UNDERSTANDING THE WAVEFORMS continued...



Note:

During increased engine speed or load the only significant change in the waveform is in the Main injection event (c) where the Hold Duty Cycle is extended to allow more fuel to be injected!

CRD Solenoid waveform over 10 milliseconds - Opposing Injection Event



CRD Solenoid - Voltage vs. Current waveform - Opposing Injection Event

A	Current trace	B	Voltage trace (+V)
C	Voltage trace (-V)		

When the crankshaft has turned 360° the opposing cylinder is on the firing cycle. The ECU control leaves the Low Side Transistor open. Because the solenoid coil is simply a resistor, a resistor without current flow will display the same voltage on both sides. Therefore the +V (B) and -V (C) traces are virtually identical.

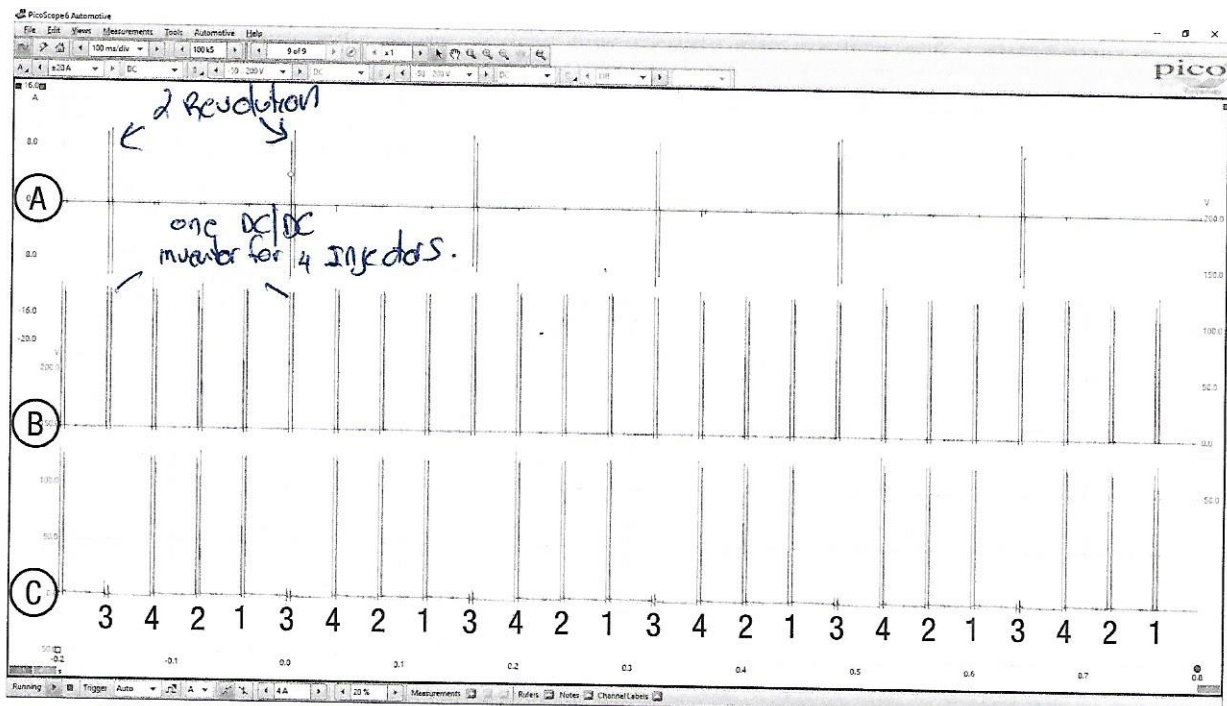
These voltages confuse many technicians, however the proof lies in the current flow and it can be clearly seen on the current trace (A) that no current is flowing.

UNDERSTANDING THE WAVEFORMS continued...

CRD Piezoelectric Injection - Voltage vs. Current

Piezoelectric Injectors work differently to any other injectors and an entirely new approach to reading the waveforms is required.

CRD Piezoelectric waveform over 1 second



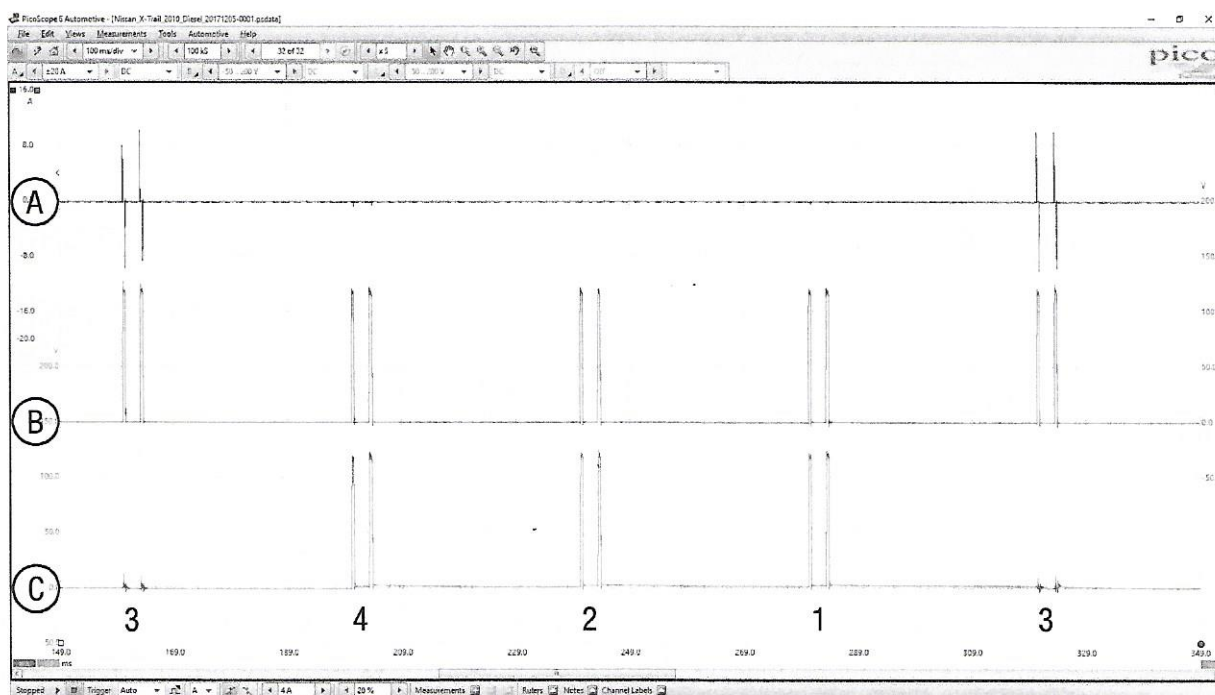
CRD Piezoelectric - Voltage vs. Current waveform

A	Current trace	B	Voltage trace (+V)
C	Voltage trace (-V)	1	Cylinder #1
2	Cylinder #2	3	Cylinder #3
4	Cylinder #4		

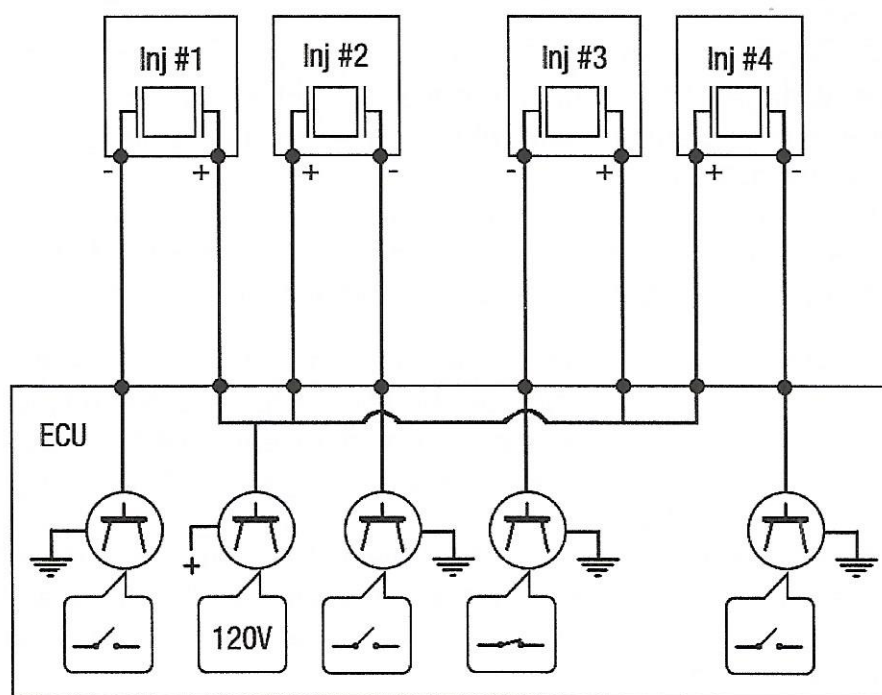
This waveform shows the relationship between the injector control between all cylinders. The bottom two traces are voltage at both sides of injector #3 (easiest to access). The top trace is current flow at injector #3 and clearly shows that while there is only current flow at every fourth cycle, no current flow means that the injectors are not responding to the voltage signals. Current flow at the injector coincides with the closure of the ground circuit on the low-side circuit. This is explained in more detail in the following two waveforms.

UNDERSTANDING THE WAVEFORMS continued...

CRD Piezoelectric waveform over 200 milliseconds



In this waveform we have the same data as the previous page but at 1/5th the time scale. This now allows the pre-injection and main injection events to be seen. This waveform was taken with the engine idling at normal operating temperature, under the right conditions some vehicles have up to seven injections per cycle.



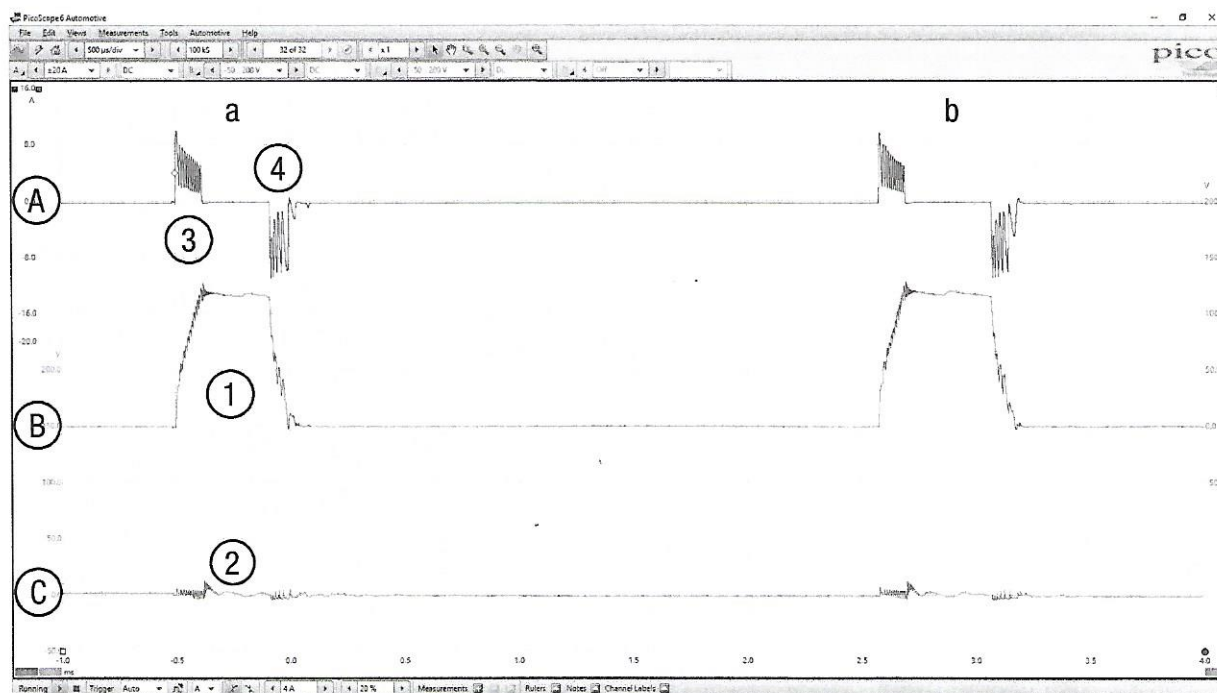
The 2010 Nissan X-Trail T31 with M9R engine used in this example uses a single High Voltage DC/DC Converter for all cylinders which is located in the Engine ECU (simplified circuit example).

Also can Kill you due to DC Amps,

Don't pull Injector plug as the Injector can remain open & bend on ends

UNDERSTANDING THE WAVEFORMS continued...

CRD Piezoelectric waveform over 5 milliseconds - Injection Event



CRD Piezoelectric - Voltage vs. Current waveform - Injection Events (x2)

A	Current trace	B	Voltage trace (+V)
C	Voltage trace (-V)	a	Pre-injection event ($\approx 0.5\text{ms}$)
b	Main Injection event ($\approx 0.6\text{ms}$)	1	On-time Voltage ($\approx 125\text{ Volts}$)
2	-V Grounded ($\approx 0\text{ Volts}$)	3	Opening Current ($\approx 10\text{ Amps}$)
4	Closing Current ($\approx 10\text{ Amps}$)		

1. The High Voltage DC/DC Converter uses the voltage (1) stored in the capacitor to create enough current flow (3) to excite the piezo crystals and open the fuel injector
2. Once the injector is opened the ECU open circuits both sides of the piezo stack, this can be seen on the waveform because the current stops flowing (between point 3 & 4) but the voltage (1) remains at 125 Volts



Note:

The easiest way to understand piezoelectric injector operation is to consider the piezo stack as a capacitor, once energised it holds the charge until it is provided a ground to discharge!

3. When the ECU wants to close the fuel injector it will ground the high-side (+V), this allows the charge held in the piezo stack to discharge and contract closing the injector. The discharging can be seen by the reverse current flow (4) measured by the current clamp.



Note:

The current used to excite the piezo stack is virtually identical to the amount discharged!

UNDERSTANDING THE WAVEFORMS continued...

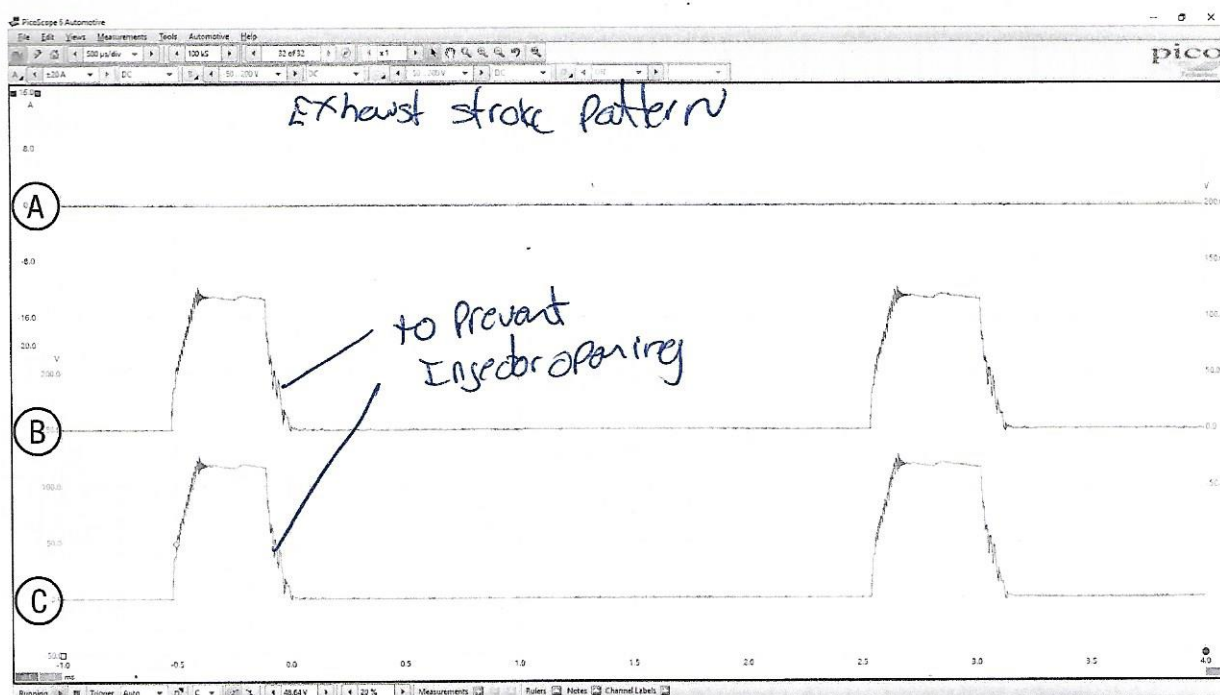


WARNING:

DO NOT UNPLUG THE INJECTOR WITH THE ENGINE RUNNING AS THERE IS A RISK OF ELECTRIC SHOCK!

IT MAY BE POSSIBLE TO CAUSE THE INJECTOR TO BE LEFT OPEN!

CRD Piezoelectric waveform over 5 milliseconds - Opposing Injection Event



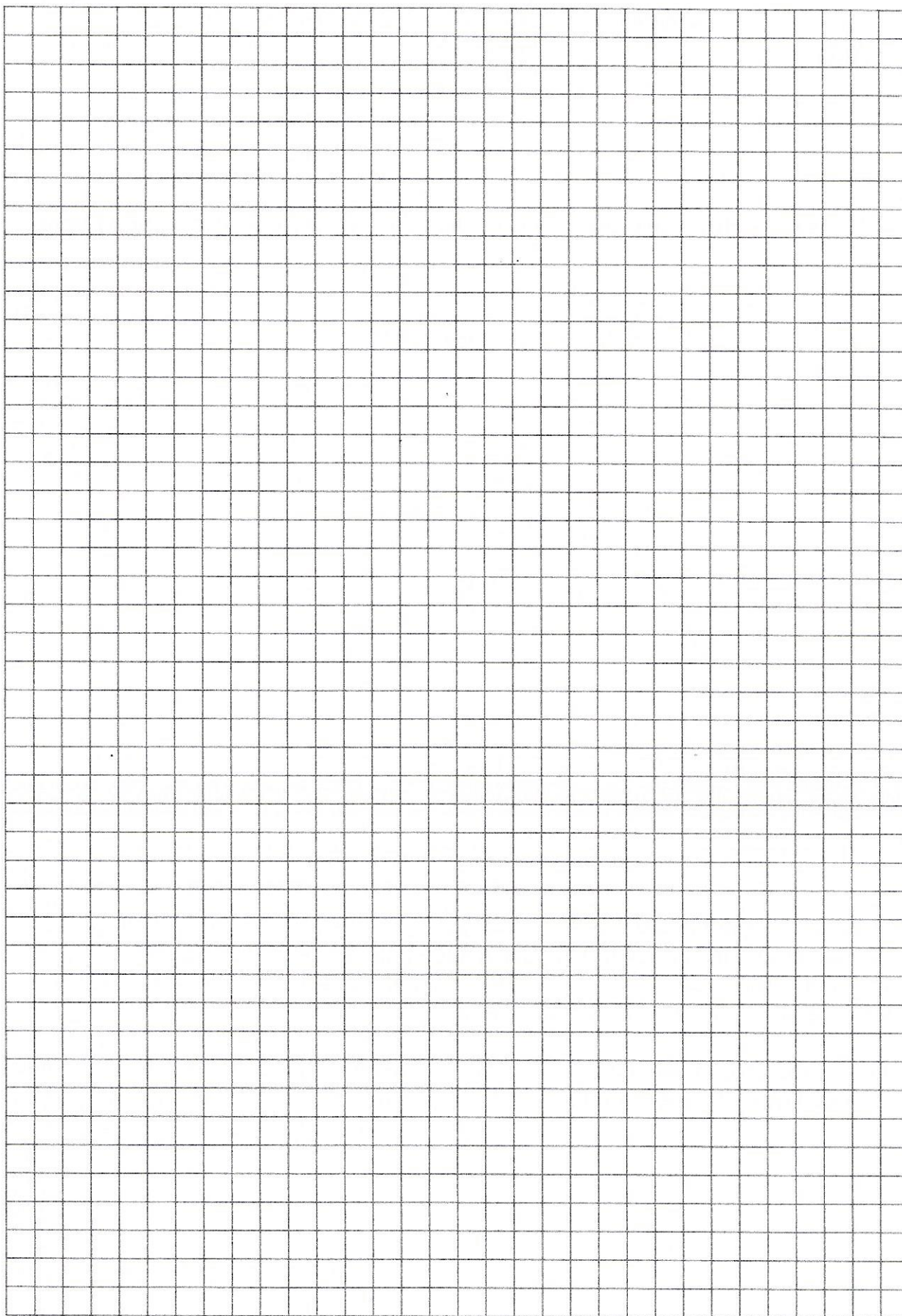
CRD Piezoelectric - Voltage vs. Current waveform - Opposing Injection Event (x2)

A	Current trace	B	Voltage trace (+V)
C	Voltage trace (-V)		

Because all cylinders are sharing the single high-side driver and High Voltage DC/DC Converter, the high-side (+V) gets voltage pulses every 180° rotation of the crankshaft. This means that identical waveforms are found on both the +V (B) and -V (C) traces for 3 out of 4 injection events.

These voltages confuse many technicians, however the proof lies in the current flow and it can be clearly seen on the current trace (A) that no current is flowing.

NOTES



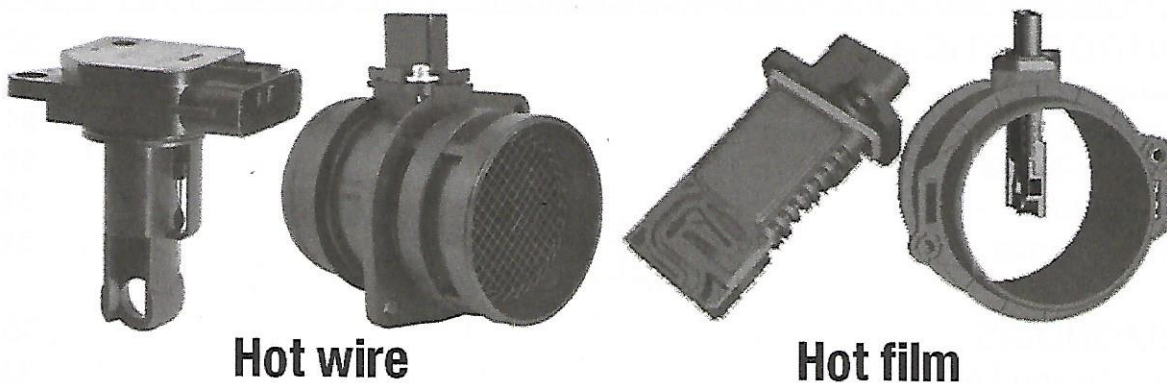
Section ii**MAF Diagnosis****CONTENTS**

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INTRODUCTION

In the modern vehicle there are only two types of MAF Sensors, the Hot-Wire type and the Hot-Film type. A generalisation can be made in regards to origin (as with all generalisations there are variants). Japanese derived vehicles tend to use the hot-wire type while European vehicles tend to use the hot-film type. Australian, American and other world cars licence one of these two forms.

Both types are available in the compact 'Plug-in' type as well as the fully 'Housed' option:



In addition to the sensors, MAF sensor diagnostics needs to consider the entire area between the Air Filter Housing and the Intake Manifold. Even exhaust blockages can interfere with the MAF values.

INTRODUCTION continued...

Sample Size

Modern Mass Air Flow Meters use a venturi to draw a sample of air from the stream. The theory is that the velocity of any contaminant particles in the air stream prevents them from 'turning the corner' and entering the sample chamber and therefore reducing contamination. This process has been so successful that MAF Meters no longer require a burn-off cycle. But the reality is that over time contaminants will reach the sensor elements and reduce their ability to measure air flow accurately. As the MAFM only samples a very small portion of the air entering the engine, it relies heavily on the control of vortices and air lamination for air entering the meter.



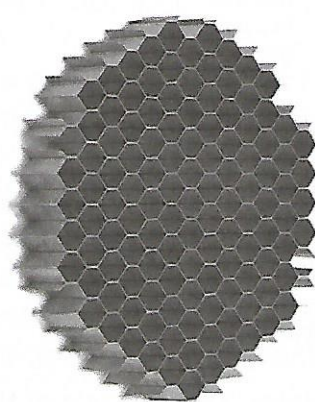
Bore Diameter $\approx 100\text{mm}$
Venturi Diameter $\approx 8\text{mm} \times 10\text{mm}$

Bore Area $\approx 7852\text{mm}^2$
Venturi Area $\approx 80\text{mm}^2$

Only about 1% of intake air is sampled.

Vortices and Air Lamination

The design of the air intake system includes one absolute goal, to deliver the air to the MAF Sensor without the forming of vortices. Vortices are helpful on the outside of barrel type air filters because they throw the dust particles outwards and extend filter life. Between the Air Filter and the throttle body, vortices are not helpful. Many manufacturers employ Air Laminators to straighten the air flow.



An Air Laminator is usually a honeycomb (left) or grid (right) screen between 5 and 10mm in depth and is located a short distance upstream of the MAFM!



Note:

Carefully consider these factors before performing diagnostics:

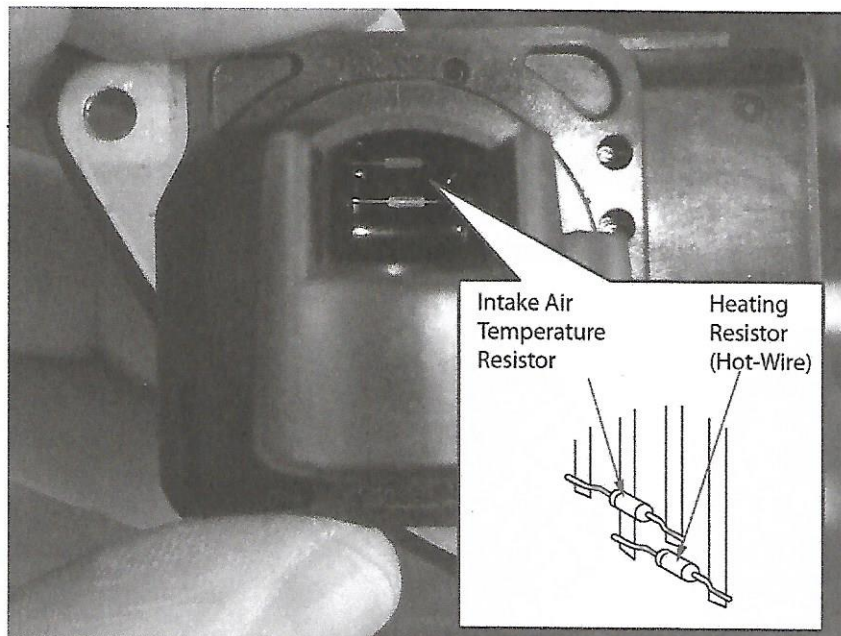
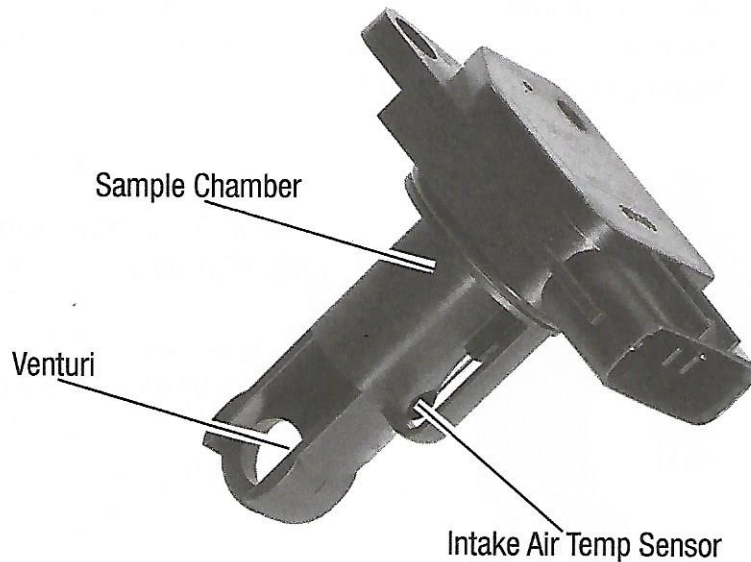
- Is the air filter the correct type?
- Has the air intake track been modified?

INTRODUCTION continued...

Sensor Types

Hot-wire type sensors

The Denso Hot-wire Sensors contain three elements, an intake air temperature sensor (used for MAF calculation only) and the sensor element known as the 'Hot-wire' are located in the sample chamber, plus there is an Intake Air Temp Sensor used by the ECU located in the main air stream.

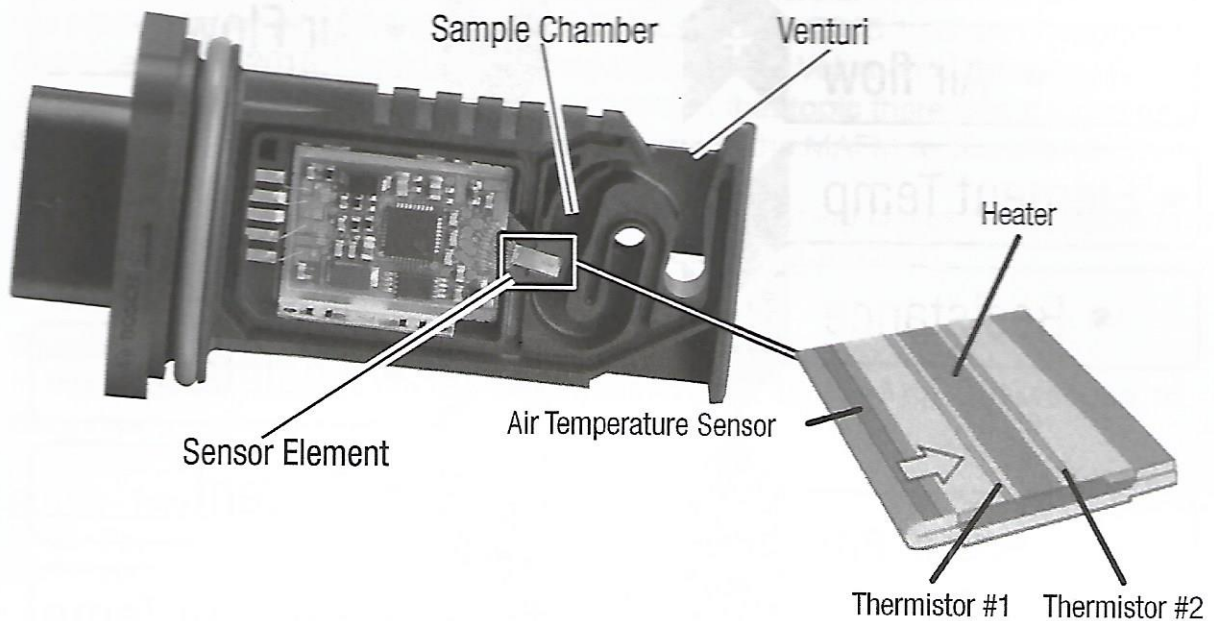


The intake air sample is drawn over the Air Temperature Resistor. The ECU uses the this value to calculate the reference temperature and control the 'Hot-wire'. As the intake air sample travels past the hot-wire it draws heat from the resistor decreasing its resistance and therefore increasing the current flow across the circuit, the current is converted into a proportional voltage value in the MAF Meter's internal circuits and monitored by the ECM.

INTRODUCTION continued...

Hot-film type sensors

The evolution of the Bosch MAF Meter has seen the sensing element become a layer of film mounted to a board rather than a wire strung between posts. While the principle operation remains the same Bosch claims that the film design is more accurate than the 'Hot-wire' alternative.



The intake air sample is drawn over the sensor element, it first passes over the Air Temperature Sensor, this value is used to calculate and control the Heater temperature (100-200°C above ambient air temperature).

The heat from the heater travels outward beyond Thermistors #1 and #2. As the intake air sample passes over Thermistor #1 the ECU monitors its temperature. The intake air sample then passes over the Heater and then over Thermistor #2 where the ECU monitors its temperature again.

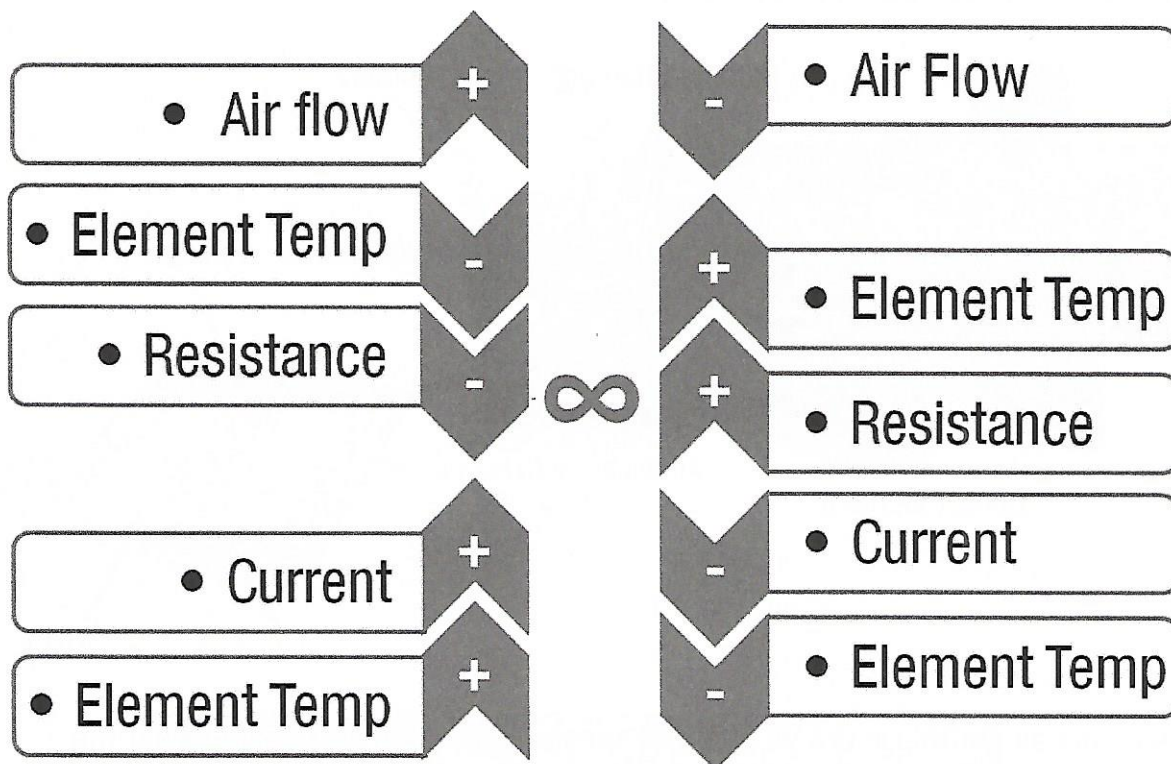
The greater the mass of air that passes over the sensor the greater the difference in temperature between Thermistor #1 and Thermistor #2.

The Bosch Hot-film MAF Meter has a unique ability: the phenomenon known as 'Return flow', where under certain conditions intake air ricochets off the back of the intake valves as they snap closed. When this occurs the ECU sees that the air at Thermistor #1 is greater than Thermistor #2, it knows that the air is passing in the wrong direction and removes it from its intake calculation.

INTRODUCTION continued...

Operation

All MAF Meters function on the principles of Ohm's Law and the relationship between Voltage, Current and Resistance. The following diagram expresses this relationship in a manner that is directly applicable to the MAF Meter function.



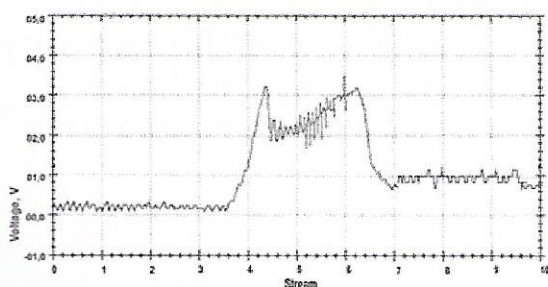
Signal Types

Analogue Sensors

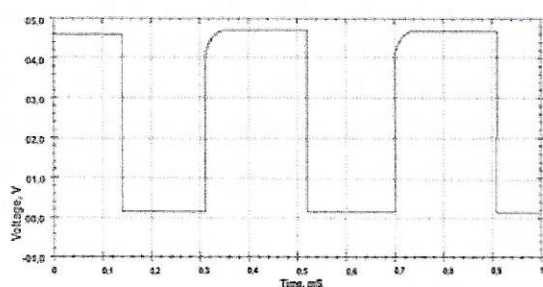
An analogue signal will have a variable voltage between 0 and 5 Volts which is directly proportional to the amount of air passing the sensor.

Digital Sensors

A digital sensor includes a processor that converts the signal into a duty-cycle with a variable frequency. Usually the duty-cycle is in the 5 Volt range, but some earlier systems are a 12 Volt duty-cycle.



Left: Typical analogue signal



Right: Typical digital signal

DIAGNOSIS

There are generally two reasons for testing the Mass Air Flow Meter:

- Lean DTC's
- Mass Air Flow Sensor DTC's

Diagnosing Lean DTC's

If the vehicles faults are related to Lean DTC's and there are no MAFM DTC's then the procedure for pinpointing the cause in Masterclass 2015.1 will be a helpful resource. In the 2015.1 topic Diagnosing Lean DTC's, Volumetric Efficiency (VE) was used as a tool to narrow down the cause. In that topic there was a focus ruling out all other possible causes and therefore leaving the MAFM as the offender.



Note:

Manuals for past training clinics are available from Auto-Tech, call 1300 300 352

Diagnosing MAF Sensor DTC's

In this topic we focus on the use a compatible Scan Tool and an Oscilloscope, to diagnose vehicles with MAF Sensors DTC's:

P0100 - Mass air flow (MAF) sensor - circuit malfunction

- For analogue MAF sensors this code will normally be activated with codes P0102 & P0103
- For digital MAF sensors this code will be logged when there is a short (ground, 5V or 12V).

P0101 - Mass air flow (MAF) sensor - range/performance problem

For vehicles that are fitted with both a MAFM and a MAP sensor, it may run a correlation comparison between these two sensors and the TPS throttle angle.

1. If this code is logged, address all other MAF, MAP & TPS DTC's first
2. Then check for air leaks between the MAF and the Throttle Body
3. MAF contamination is also a factor for this DTC, carry out a visual inspection
4. Use scan tool data to assess the operational parameters of MAF, MAP & TPS

P0102 - Mass air flow (MAF) sensor - low input

- The voltage or frequency signal to the ECU is below the lower threshold.
- For analogue MAF sensors this will mean a signal below 0.2-0.5 Volts
- For digital MAF sensors this will mean a signal below 500-1150 Hz
- For 3-30 Seconds at idle

P0103 - Mass air flow (MAF) sensor - high input

- The voltage or frequency signal to the ECU is above the higher threshold.
- For analogue MAF sensors this will mean a signal above 4.5 - 4.8 Volts
- For digital MAF sensors this will mean a signal below 14-15 kHz
- For 3-30 Seconds at idle

DIAGNOSIS continued...

P0104 - Mass air flow (MAF) sensor - circuit intermittent

- The parameters for setting a P0104 are less generic. However, the most common use of this DTC is to log this code after codes P0100-P0103 have been cleared due to inactivity over a prescribed number of drive cycles.

P0068 - MAP sensor/MAF sensor - throttle position correlation

For vehicles that are fitted with both a MAFM and a MAP sensor, it may run a correlation comparison between these two sensors and the TPS throttle angle.

1. If this code is logged, address all other MAF, MAP & TPS DTC's first
2. Then check for air leaks between the MAF and the Throttle Body
3. MAF contamination is also a factor in this DTC, carry out a visual inspection
4. Use scan tool data to assess the operations parameters of MAF, MAP & TPS

OE Diagnostic Information

Manufacturers only provide a broad spectrum for overall sensor range, for example:

- 0.5 to 4.5 Volts
- 0.9 to 630 grams per second (g/s)
- 800 to 14,500 Hertz (Hz)

1.0 ± 0.2 g/s per litre of eng displacement.

This is rarely broken down into the amount one would expect to see in certain operating conditions.

Scan Tool Data

Using Scan Tool Data alone to assess a MAFM issue is not terribly helpful, this is mainly due to a lack of supporting data from the manufacturer. As vehicles vary dramatically in displacement, RPM, load and efficiency the values vary substantially.

Grams per Second (g/s) is the only MAFM value provided on many vehicles. There is a rule of thumb that suggests that at idle you should see approximately 1 g/s of air mass for each litre of engine displacement. Through extensive testing and analysis this rule does have some merit but is not fool proof. Firstly it applies only to petrol engines, secondly it needs a reasonable parameter of $\pm 20\%$ and lastly it does not appear to be accurate for the latest high efficiency down-sized engines (e.g. 1.2L DPI turbocharged).

If Scan Tool Data includes voltage outputs it is possible (but not recommended) to use the values provided on the following pages and apply them to the Scan Tool Data Graphs.



Caution:

Scan Tool Data is processed data that is output to the Scan Tool by the ECU. It is never the exact values of the component in real time and is often calibrated with other values!

OSCILLOSCOPE WAVEFORMS

Using an oscilloscope to analyse the MAFM is by far the most accurate testing method. There is little need to access wiring diagrams as most Mass Air Flow Meters have 5 wires:

- Power Supply - Always Battery Volts
- MAF Ground - Always less than 100 millivolts
- MAF Signal - Variable Volts (analogue) or Duty Cycle (digital)
- Intake Air Temp Ground - Always less than 100 millivolts
- Intake Air Temp Signal - Variable volts but stable



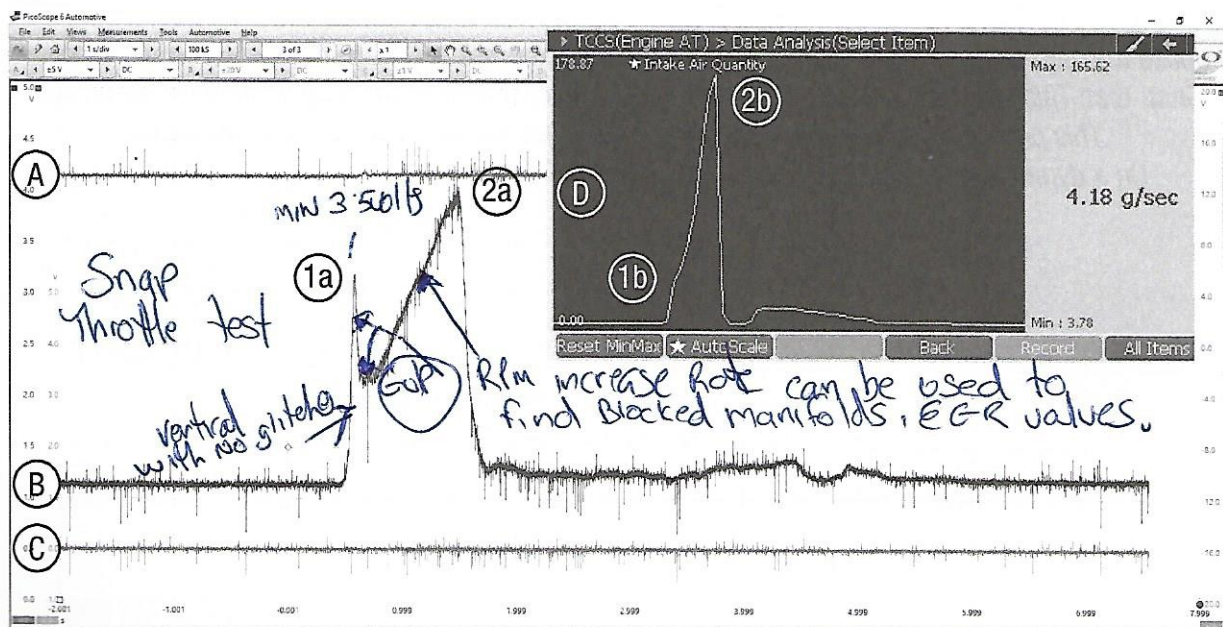
Note:

With a single oscilloscope lead and its channel set to 0 to 20V, backprobe all terminals of the MAFM. The MAF signal will be evident quickly!

After checking that the power and ground circuits are in good order, leave the lead in the signal terminal. Allow the engine to idle until it reaches normal operating temperature with the A/C and all electrical loads turned off.

Analogue Sensors on Naturally Aspirated Petrol Engines

At idle you should see 1.2 ± 0.3 Volts continuously. When the throttle is snapped to wide open and then released as engine reaches its rev limiter the following waveform is generated.



Hot-wire Analogue - Mass Air Flow Meter - Throttle Snap

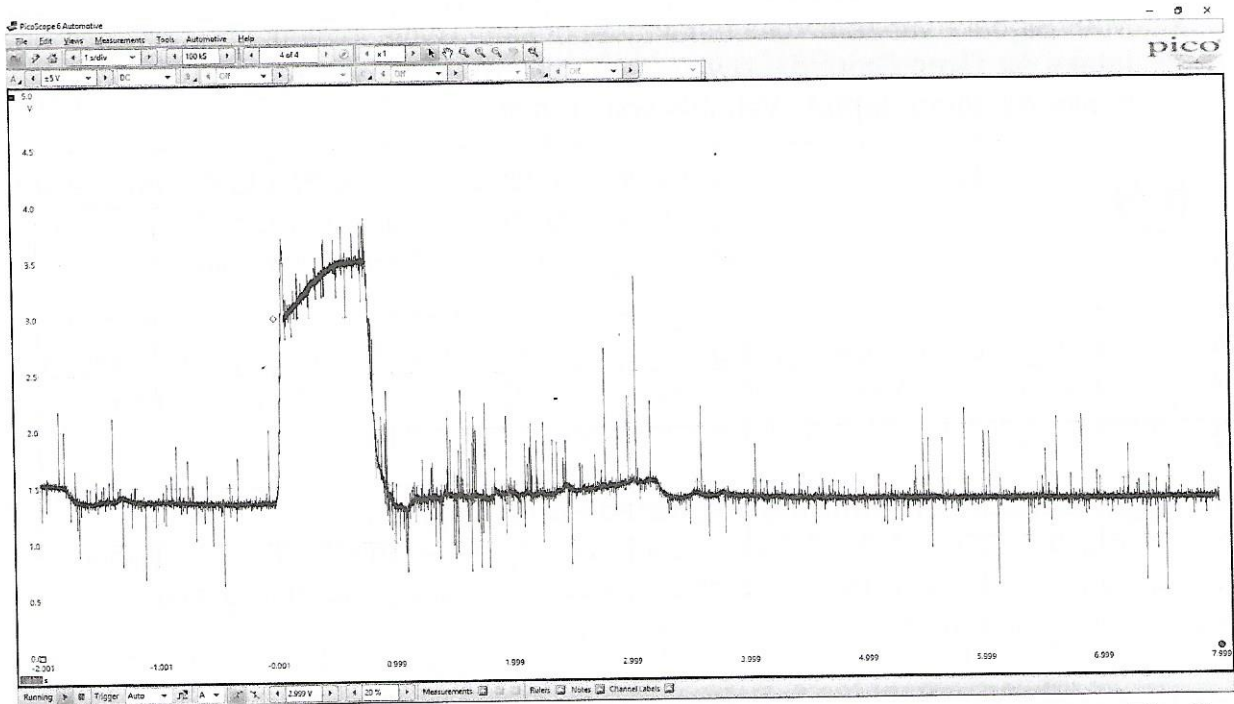
A	Power Supply trace (13.5 Volts)	B	Signal trace (0.5 to 4.5 Volts)
C	Ground trace (less than 100mV)	D	Scan Tool Data graph of the same event
1a	Gulp clearly visible	1b	Gulp barely visible
2a	Peak voltage should be ≈ 4 Volts	2b	No general value for peak g/sec

Don't use scan tools to do this test (sample rate too slow).
 Petrol Turbo engines lose the Gulp pattern due to boost.
 Diesel engines have a different pattern to above due to no vacuum ect.

OSCILLOSCOPE WAVEFORMS continued...

Analogue Sensors on Turbocharged Petrol Engines

At idle you should see 1.2 ± 0.3 Volts continuously. When the throttle is snapped to wide open and then released as engine reaches its rev limiter the following waveform is generated.



Unlike it's naturally aspirated counterpart the Turbo engine will not reach the 4 Volts on the Throttle Snap Test. This is because the turbocharger does not have time to spool up limiting the air intake.

This produces a more linear increase in air mass between the gulp and the peak.

On a dynamometer or road test a value closer to 4.5 volts should be able to be achieved.

OSCILLOSCOPE WAVEFORMS continued...

Analogue Sensors on Turbocharged Diesel Engines

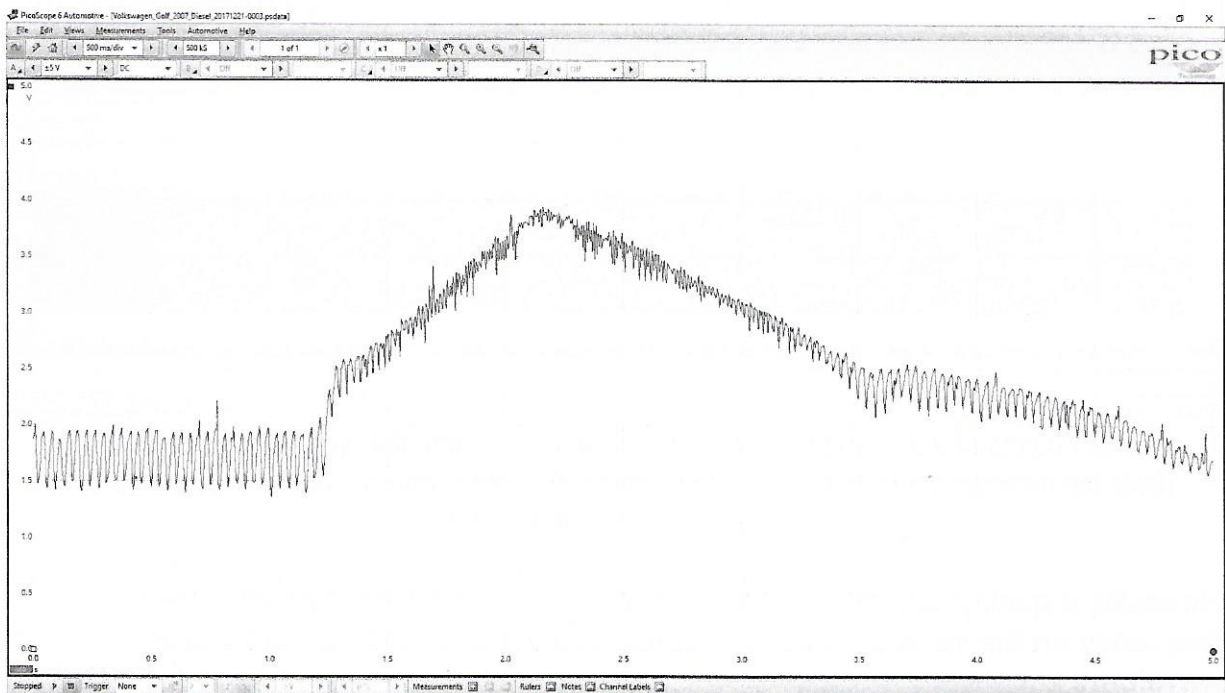
Diesel vehicles will vary their idle air intake dramatically. Diesels naturally run lean at idle without intake restriction, this results in a much higher value MAF value. When the ECU commands EGR Flow, the throttle actuator restricts the intake flow in order to create a low pressure in the intake manifold to enable EGR gases to flow. The EGR gas flow can be substantial with a noticeable drop in air intake mass.



Note:

The low pressure created for EGR gas flow is minimal, it will not create a manifold vacuum as seen on petrol engines!

When the accelerator pedal is snapped to wide open and then released as engine reaches its rev limiter the following waveform is generated.



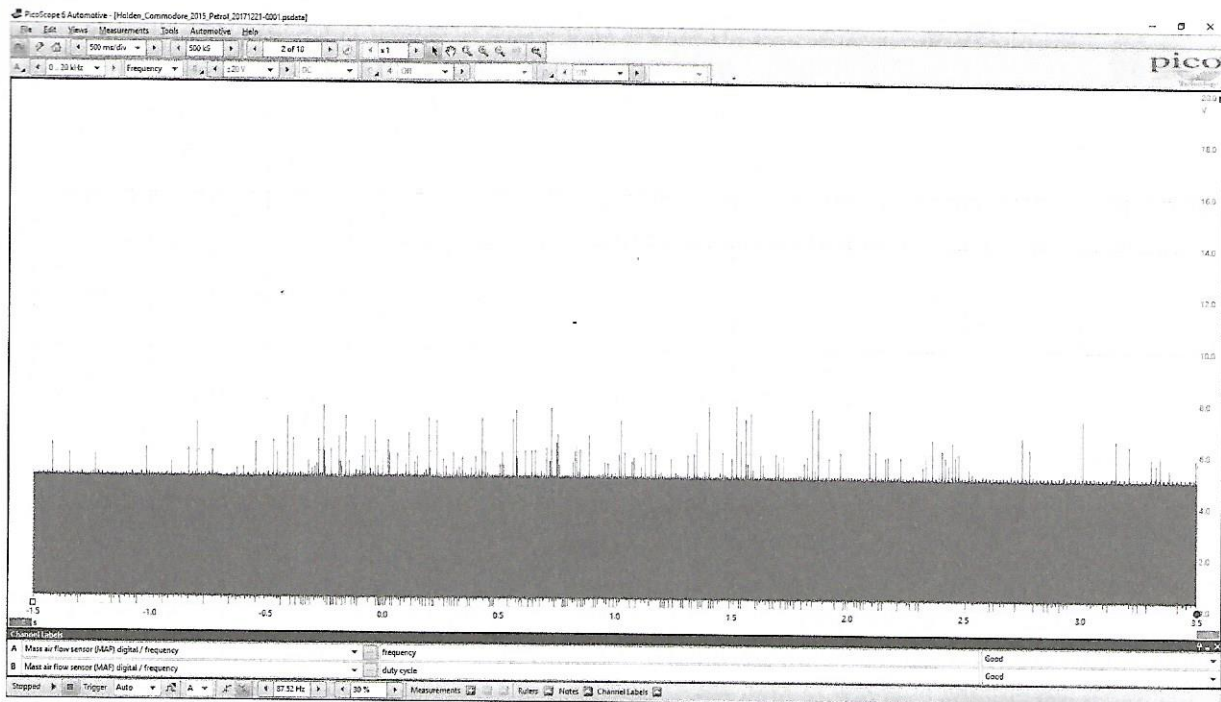
Because there is no manifold vacuum a diesel engine will not take in a gulp of air, instead a much more linear rise and fall is typical. It is also worth noting that because there is no throttle plate to dampen the air pulses it is possible to see the variation in intake air volume as the inlet valves open and close especially at idle (first 1.2 seconds of the waveform).

As with the turbocharged petrol engines peak voltage is below 4 volts due to the lack of turbo boost, on a dynamometer or road test a value closer to 4.5 volts should be able to be achieved.

OSCILLOSCOPE WAVEFORMS continued...

Digital Sensors

The difference between an analogue and a digital output is that the values have been processed in the sensor which improves the response time a tad. The duty cycle remains constant ($\approx 50\%$) but the frequency increases with air flow. The digital waveform on its own does not provide an easily decipherable picture of the sensors operation.



Raw output of the duty cycle from a Holden VF Commodore during Throttle Snap Test. While the measuring tool can be used to count the frequency values it does not provide a user friendly or efficient representation.

However, a quality automotive oscilloscope will allow the operator to select frequency on the vertical scale, this option produces a much more familiar waveform.

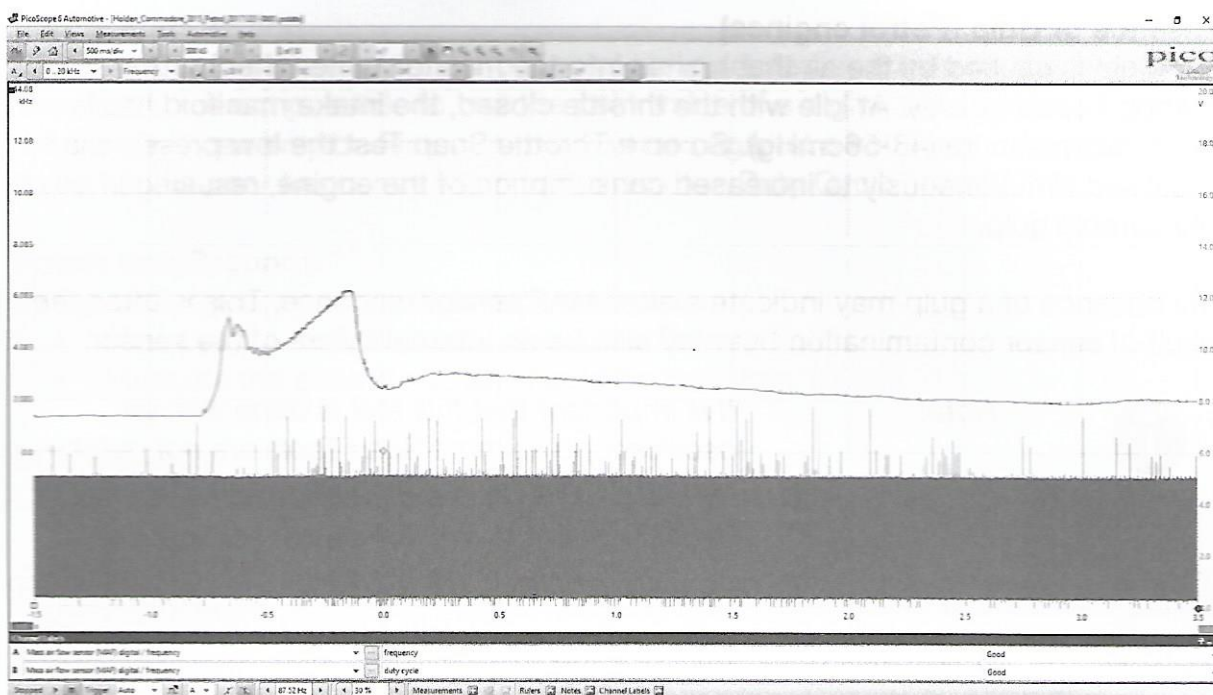
With the frequency displayed graphically, the gulp and peak typical of a naturally aspirated petrol engine are visible. Unfortunately the peak value cannot be measured against a general rule. In this Throttle Snap Test the frequency reach $\approx 7\text{kHz}$, Holden states that the operation range is up to 14.5kHz .



Note:

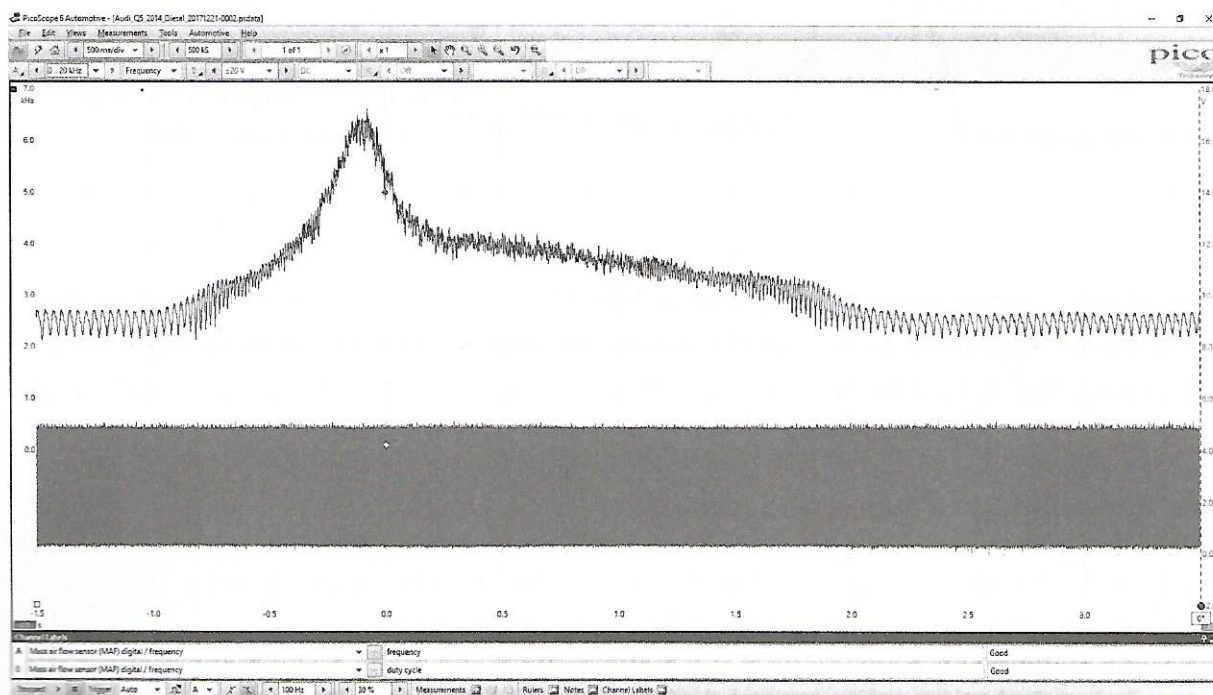
These tests were carried out on a known good vehicle!

OSCILLOSCOPE WAVEFORMS continued...



*Lower trace: Raw output of the duty cycle from a Holden VF Commodore during Throttle Snap Test.
Upper trace: Same duty cycle signal as the lower trace, except displayed as frequency over time.*

Similarly, when this testing method is applied to a turbo diesel vehicle the net result is a waveform not unlike the analogue alternative.



2014 Audi SQ5 V6 Diesel with digital Hot-film MAFM, Throttle Snap Test.

*Lower trace: ± 20 Volts - DC
Upper trace: 0-20kHz - Frequency
Time scale: 500ms/div*

DIAGNOSING FAULTY SENSORS

Absence of Gulp (Petrol engines)

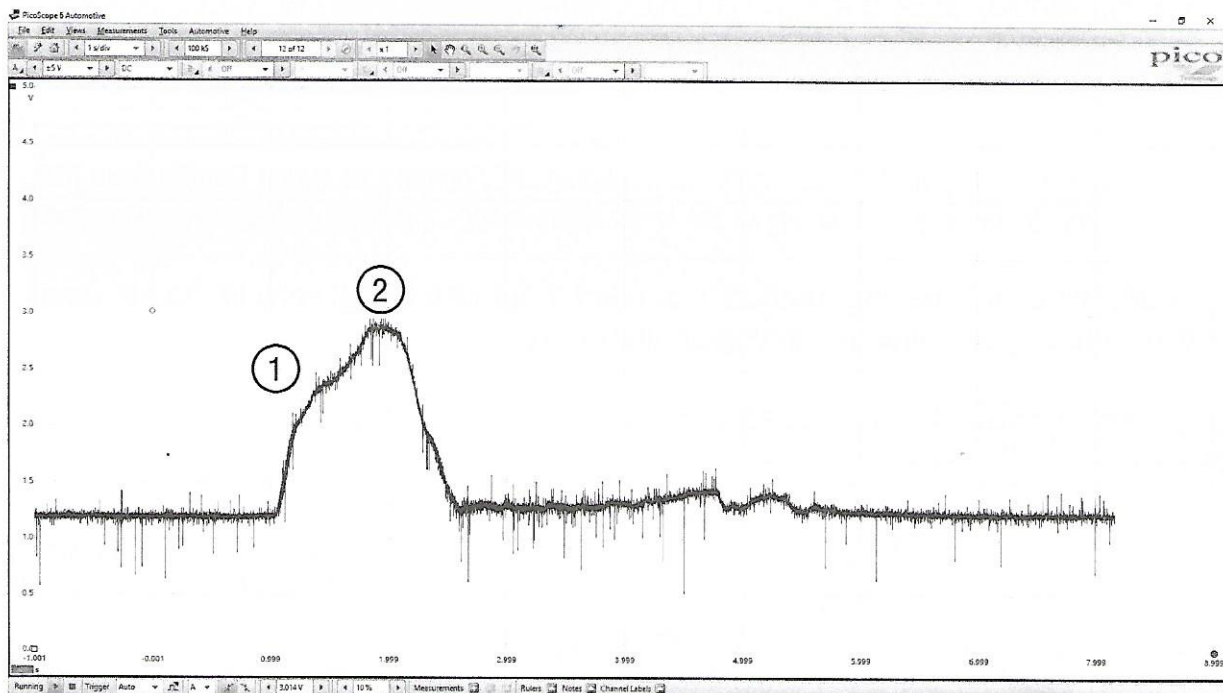
The Gulp is caused by the air that rushes into the manifold when the throttle is snapped open quickly. At idle with the throttle closed, the intake manifold has its lowest pressure (43-56cmHg). So on a Throttle Snap Test the low pressure is equalised simultaneously to increased consumption of the engine, resulting in a measurable gulp.

The absence of a gulp may indicate a slow MAF sensor response. This is often the result of sensor contamination but may also be an internal failure of the sensor.



Note:

It is important that this test is done with an oscilloscope as most Scan Tools are not quick enough to display the gulp via graphed scan tool data!



*The almost complete absence of the Gulp (1) and low Peak voltage indicates an air intake issue. Other faults that may produce a similar waveform: Low intake manifold at idle - Check with gauge
Blocked exhaust - Check exhaust back pressure if suspected*

Low Peak Voltage (Analogue Sensors)

Unlike the g/s value displayed on a scan tool which will vary with engine displacement and other factors, the sensors peak voltage value during a Throttle Snap Test is very consistent. Look for the following values:

- Naturally Aspirated engines = 4.0 to 4.5 Volts
- Turbocharged engine (petrol and diesel) = 3.5 to 4.0 volts

DIAGNOSING FAULTY SENSORS continued...

Digital MAF testing

When testing digital sensors, petrol engines should display a gulp on the frequency waveform. It is not possible to test the peak value of a digital sensor against generic values. They can only be tested for peak values against a known good vehicle. If you have a poor frequency waveform check the Duty Cycle (usually 0 to 5 Volts).

Power and Grounds

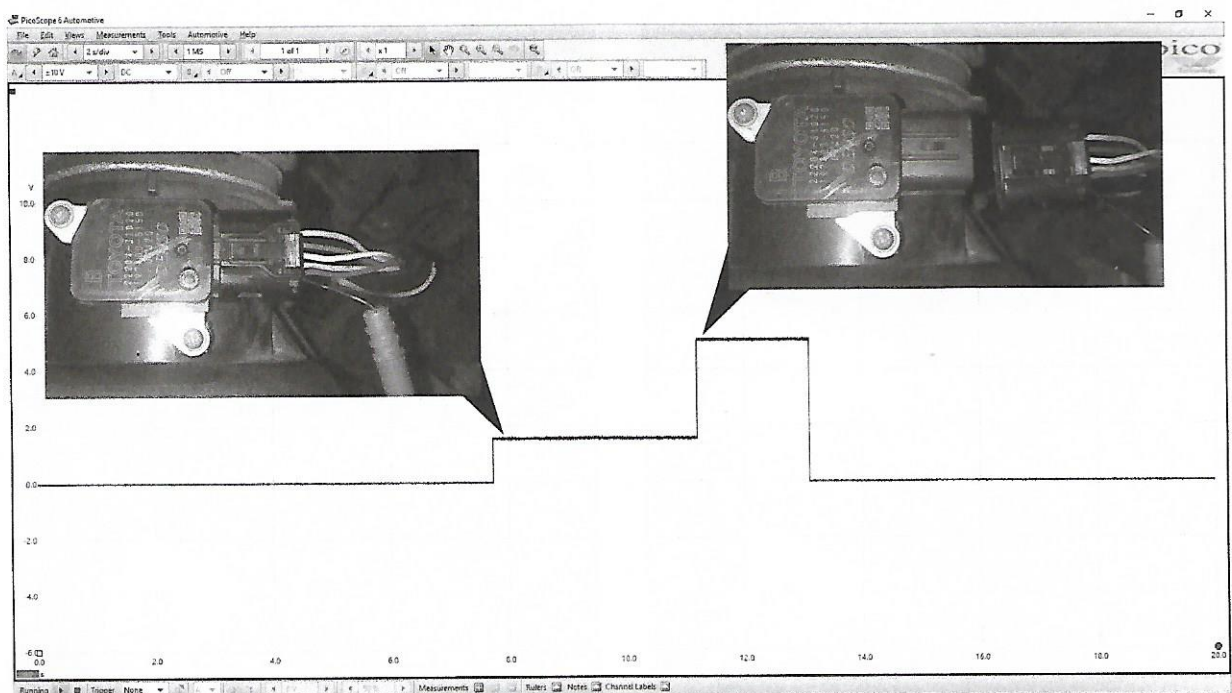
Use your oscilloscope as a high-tech multimeter.

- Measure the power supply, should be Battery Volts
- Measure the ground circuit, should be less than 100mV

ECU integrity

Check the 5 Volt reference from the ECU to the Sensor.

1. Backprobe the signal wire at the MAFM
2. Ignition ON and Engine OFF (KOEO)
3. Disconnect the MAFM connector, voltage should jump to 5 Volts

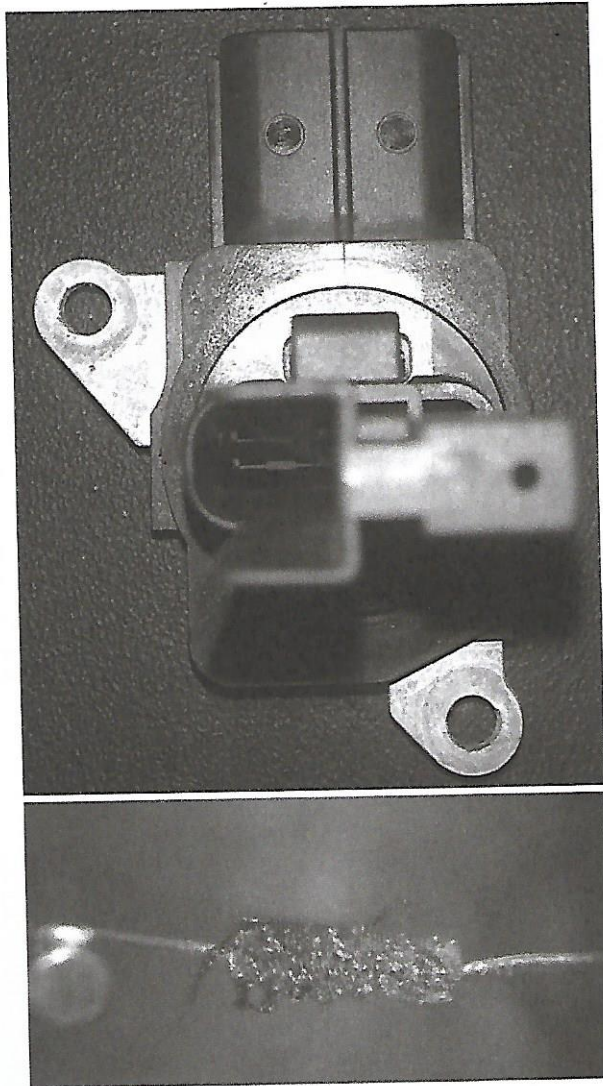


DIAGNOSING FAULTY SENSORS continued...

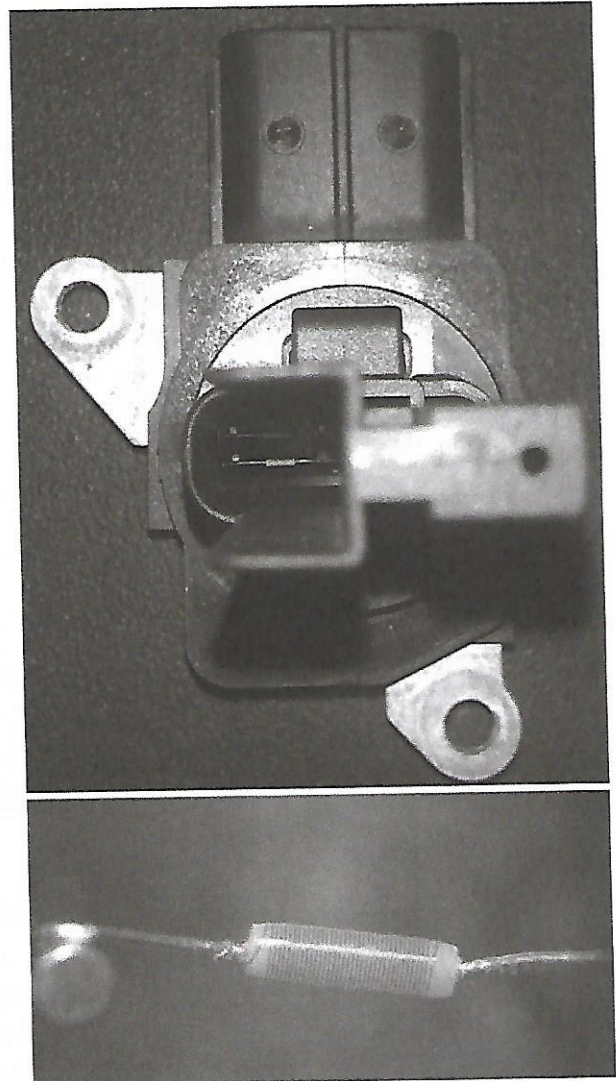
Cleaning a faulty MAFM versus replacement

The use of cleaning products on a MAFM is strongly discouraged by all vehicle manufacturers. However, there are products that are designed specifically for cleaning MAFM's and also a very large number of case studies that have shown success in achieving a favourable result. Taken into consideration is the cost difference in the two approaches.

The makers of one of the cleaning products claims that using their cleaning product each service will help to prevent a failure, but as this does not fit with the vehicle manufactures requirements this is not advised (especially during the OE warranty period). However, if a MAF sensor is proven to be operating outside of it's parameters, what harm can there be in attempting to clean the sensor before condemning it to landfill?



Dirty Hot-wire Sensor



Clean Hot-wire Sensor

Hot equivalent to a bog catcher .
after cleaning sensor can fail due to contamination

DIAGNOSING FAULTY SENSORS continued...

Misdiagnosis WARNING!

There is a phenomenon of MAF Sensor contamination that is known to throw technicians off the scent and cause a misdiagnosis for those who do not complete the diagnosis and jump to conclusions.

A contaminated MAF Sensor will reduce the amount of air measured by the sensor. This is because the contamination forms an insulating barrier around the sensor element. When this occurs the ECU will register lean running conditions at the Upstream Oxygen Sensors (UO2S) and result in an increase in fuel delivery via the Short Term Fuel Trim (STFT) and then the Long Term Fuel Trim (LTFT). So typically; MAF Sensor contamination will result in positive fuel correction values.

There are however examples where the contamination of the MAF Sensor will amplify the MAF signal at idle by increasing the surface area of the element. But once the air flow increases above idle, current cannot travel through the contaminants fast enough and it becomes an insulator. This results in very confusing and a sharp contradiction between STFT and LTFT.

Diagnosis is discussed in Chapter 5, Diagnostics with Fuel Trims.

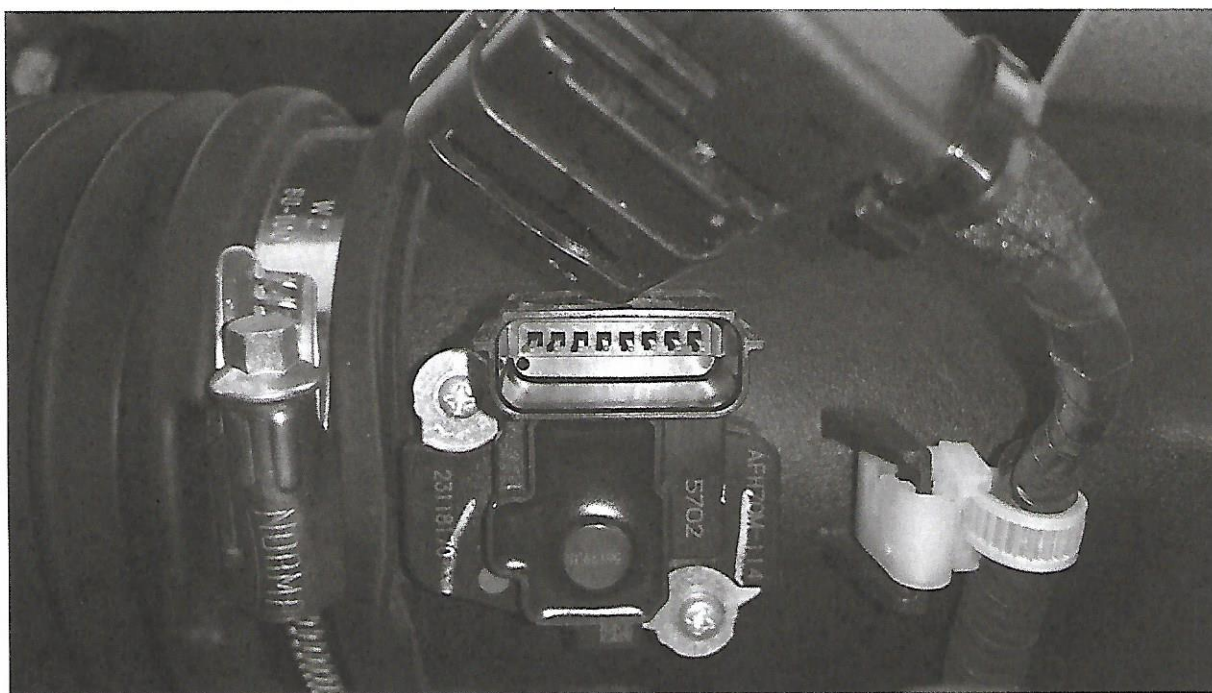
NEW TECHNOLOGY

Holden 8-wire Multifunction Intake Air Sensor

The new 8-wire Multifunction Intake Air Sensor replaces the MAFM and BARO sensors. The new sensors are made by Hitachi and incorporate:

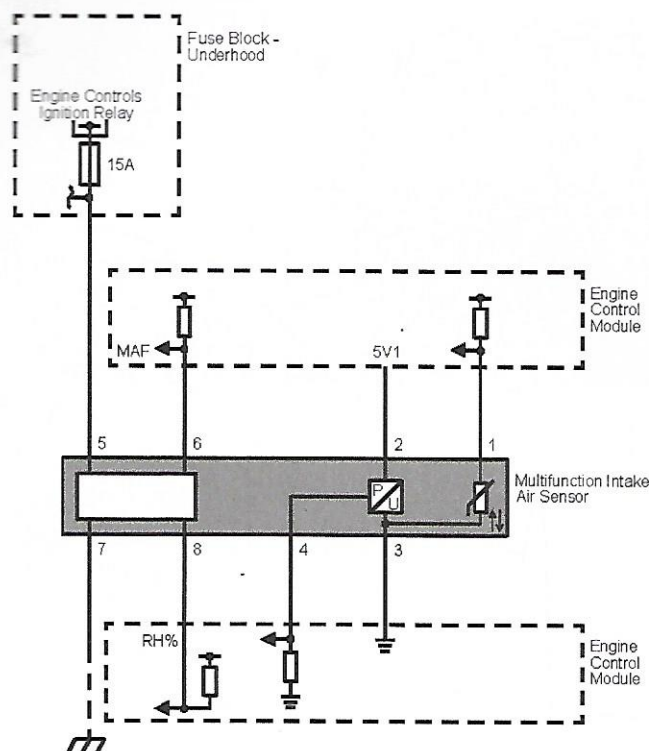
- Mass Air Flow (MAF) Sensor
- Intake Air Temperature (IAT) Sensor #1
- Intake Air Pressure (BARO) Sensor
- Relative Humidity (RH) Sensor
- Intake Air Temperature (IAT) Sensor #2

The most interesting function is that the RH and IAT2 signals are both delivered over the one signal. This is done with the use of a duty cycle where the duty ratio represents humidity (eg. 70% duty equals 70%RH) and frequency represents IAT2.



The new 8-wire sensor was introduced in the 2012MY VE Commodore.

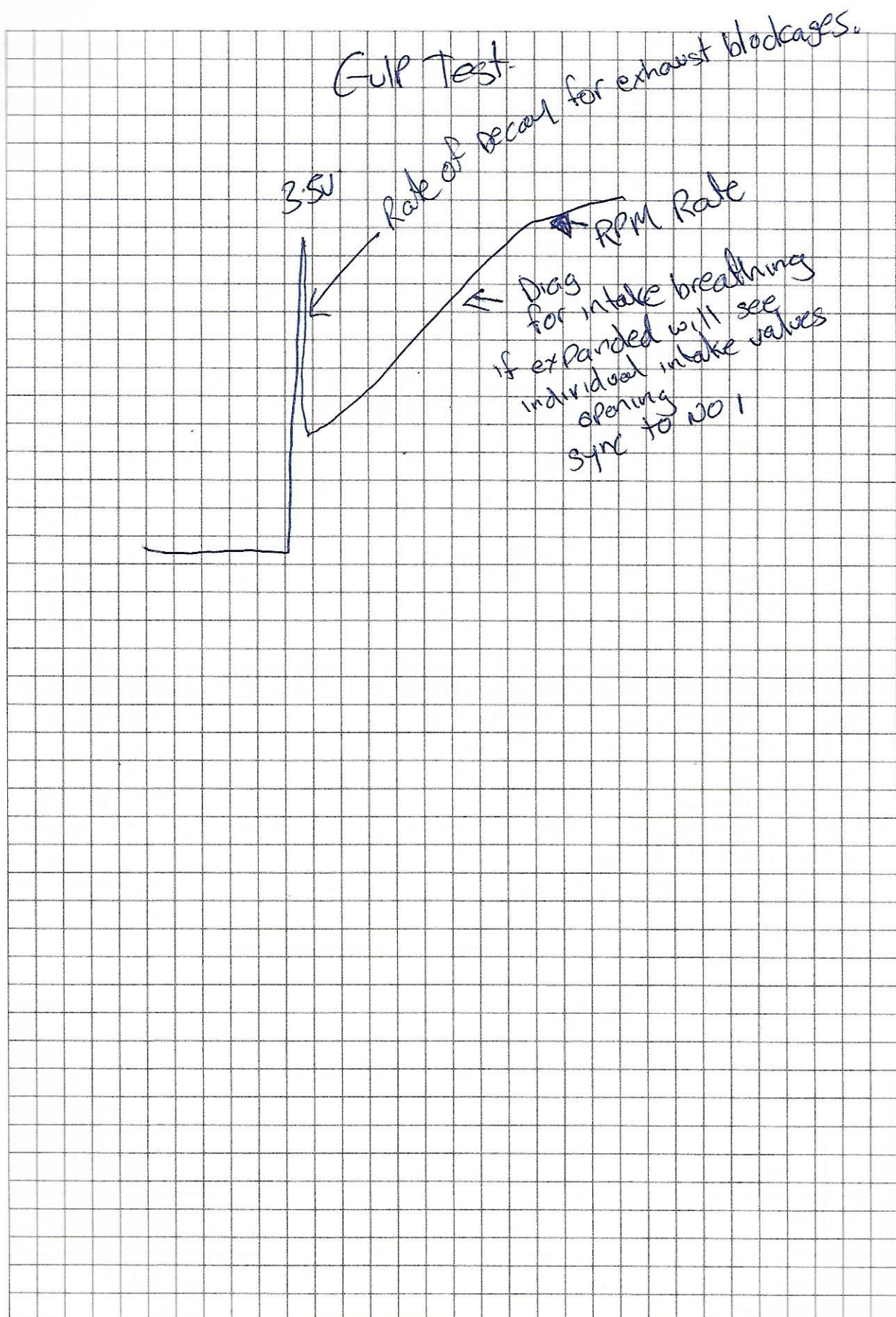
NEW TECHNOLOGY continued...



Holden 8-wire Multifunction Intake Air Sensor Circuit Diagram

Hitachi - Multifunction Intake Air Sensor				
Pin	Circuit	Scope setting	Value	Scan Tool Data
1	Intake Air Temp Sensor #1 - Signal	± 5 Volts	0.5 - 4.5 V	-38 - 149°C
2	5 Volt Reference	± 10 Volts	4.8 - 5.2 V	N/A
3	Sensor Ground	± 1 Volt	<100mV	N/A
4	Throttle Inlet Air Pressure - BARO Signal	± 5 Volts	2.0-4.5 V	56-105 kPa
5	Power Supply - MAF, RH% and IATS#2	± 20 Volts	Battery Volts	N/A
6	Mass Air Flow Sensor - Signal	Frequency	800Hz - 14.5kHz	0.9 - 630 g/s
7	Ground	± 1 Volt	<100mV	N/A
8	Relative Humidity Sensor	Duty Cycle	5-95%	5-95%
	Intake Air Temp Sensor #2 - Signal	Frequency	45 - 302Hz	-40 - 104°C

NOTES



Section iii**Air Intake Control Systems****CONTENTS**

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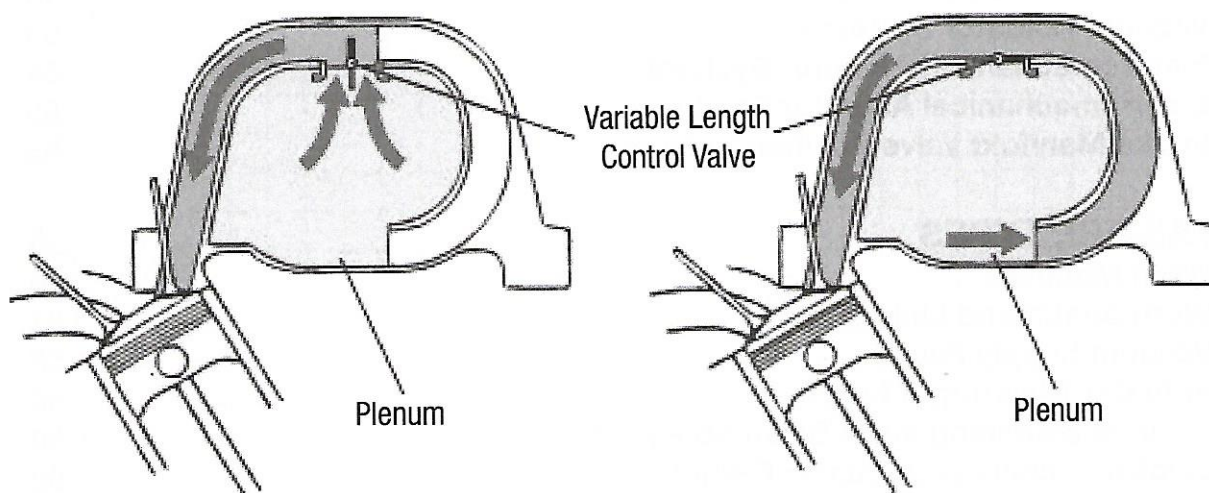
INTRODUCTION

The air dynamics of an Intake Manifold play a huge role in the air fuel mixture requirements whether that is homogeneous charge (fuel evenly distributed through the air charge) or stratified charge (different areas of air/fuel density). Intake Manifold control systems operate on three principles:

1. Variable Intake Manifold Length
2. Intake Manifold Swirl Control
3. Intake Manifold Tumble Control

Variable Intake Manifold Length

Varying the length of the intake is most beneficial on non-turbocharged port fuel injected engines. When the engine is in low to partial load the intake length is increased, this increases the velocity of the intake charge and improves the exhaust scavenging and therefore efficiency. Most commonly the longer intake path has a reduced bore size to further increase the charge velocity further. During optimal operating conditions a positive charging affect can be created in the cylinder.



Left: Valve OPEN - High Volume

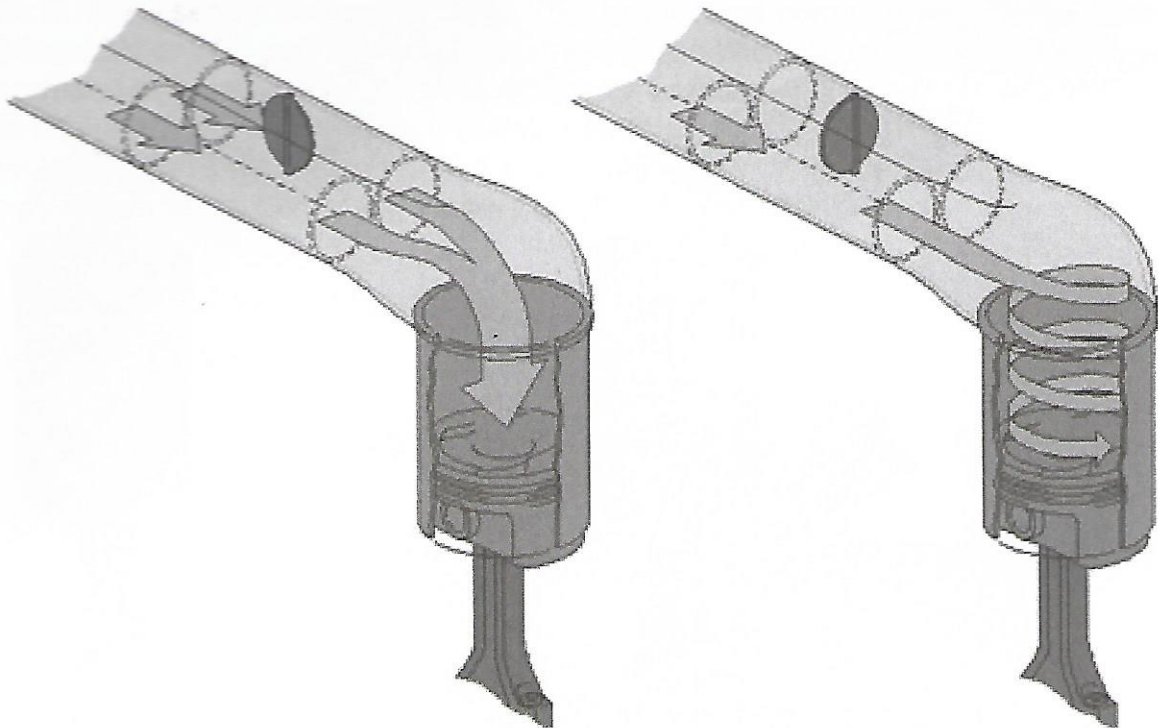
Right: Valve CLOSED - High Velocity

This is done at the sacrifice of throttle response, so if the engine is being driven harder the shorter length is employed. As the trend moves towards Direct Petrol Injection (DPI) and turbocharging, the employment of variable length systems are diminishing.

INTRODUCTION continued...

Intake Manifold Swirl Control

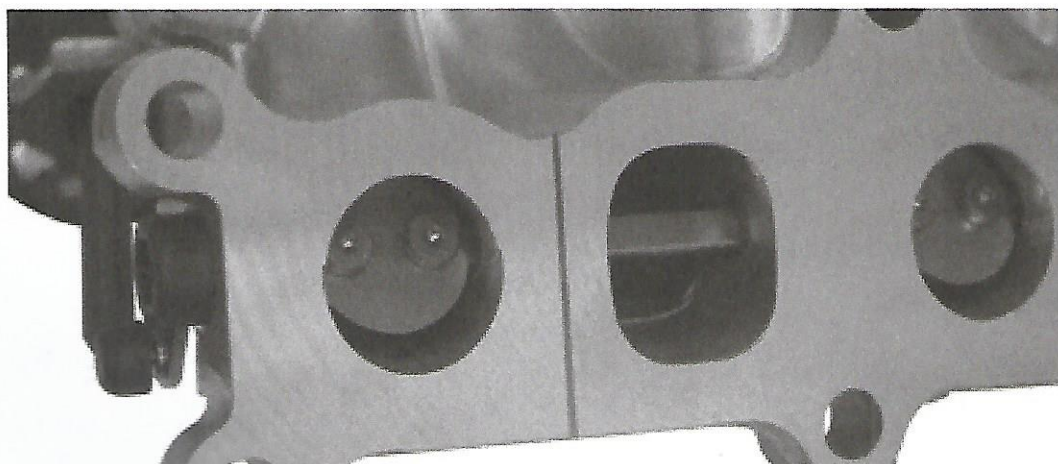
Swirl Control is focused on how the air charge enters the cylinder. It is used on many new vehicles, particularly on Common Rail Diesel (CRD) engines. Swirl control usually uses two intake channels often with different shapes, the swirl control will close one of the two channels.



Left: Valve OPEN - High Volume

Right: Valve CLOSED - Strong Swirl

In low to partial load conditions the swirl valve closes creating a strong swirl (vortex) within the combustion chamber. As the piston rises the strength of the vortex increases, this helps to hold the fuel in a dense ball in the centre of the piston. Under heavier load a higher volume of air is required so the valve is opened.

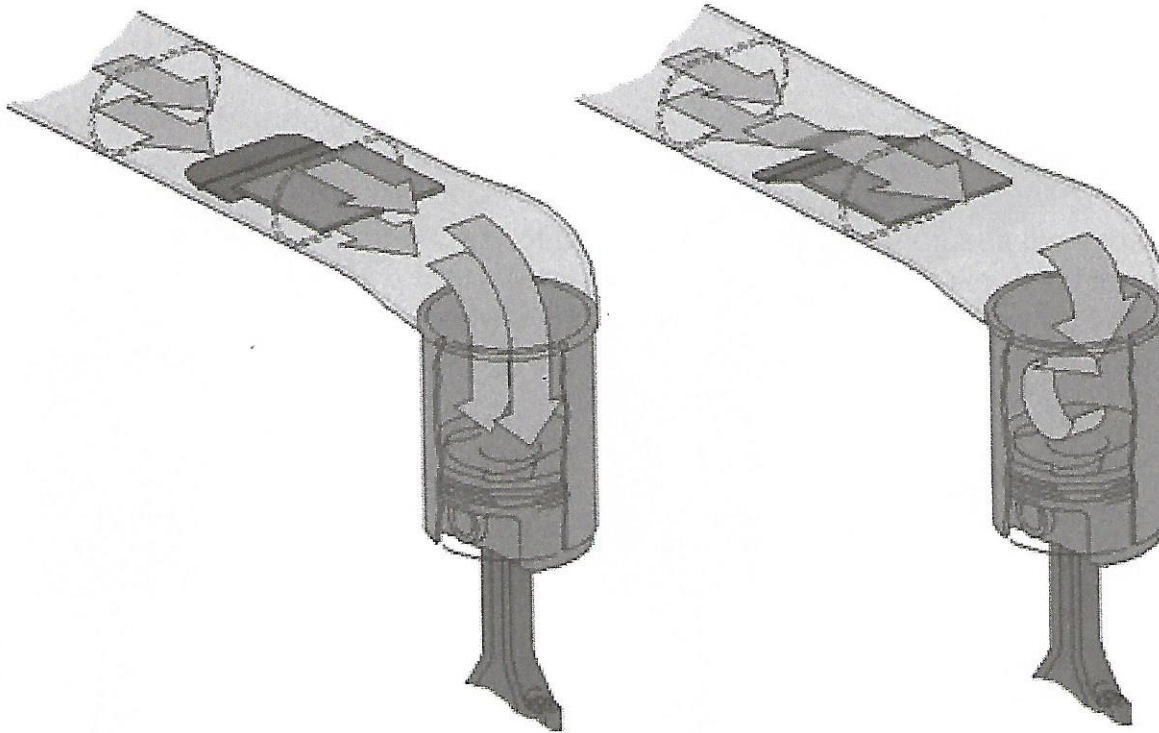


Intake swirl control valves of a Holden Astra CDTi

INTRODUCTION continued...

Intake Manifold Tumble Control

Tumble Control is also focused on how the air (DPI) or air/fuel (PFI) charge enters the cylinder. It is used on many new vehicles, particularly those using DPI. Tumble valves can be used on single or double channel intake manifold.



Left: Valve OPEN - High Volume

Right: Valve CLOSED - Tumble Effect

The tumble effect is employed during low to partial loads to create a Stratified Charge where the dense air/fuel charge held in the centre of the piston while surrounded by a tumbling mixture mainly of exhaust gases that shield the heat of combustion from the cylinder walls reducing heat losses.

In PFI systems tumble control valves are sometimes employed to assist in stabilising the combustion during lean burn strategies in much the same way as they are employed in DPI systems.

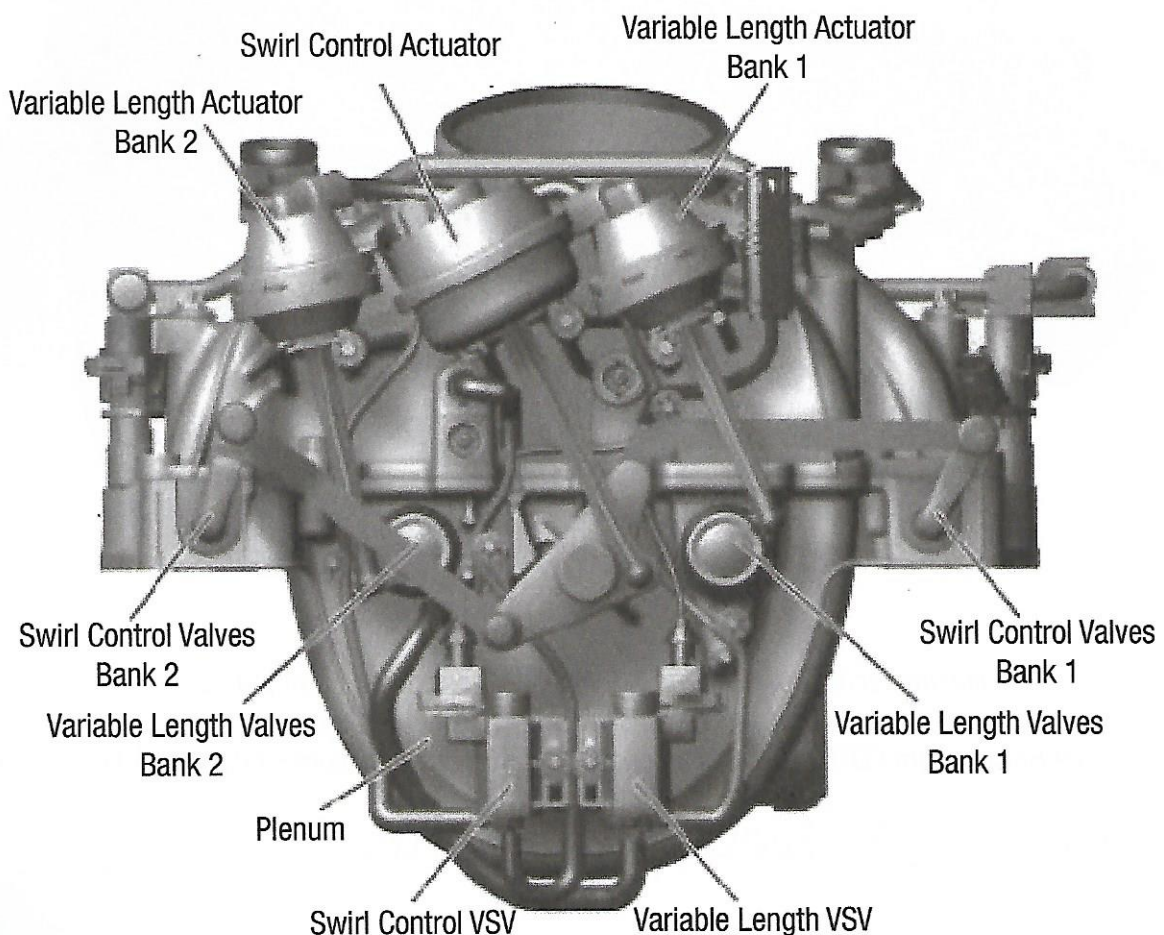
CONTROL SYSTEMS

There are typically two types of actuators used and each can be employed with or without a position sensor.

1. ECU controlled Vacuum Switching Valve (VSV) with Vacuum Actuator
2. ECU controlled Electromechanical Actuator

Vacuum Actuator Systems

The ECU will send a command to the VSV, this is most commonly a simple Battery Voltage ON or OFF command but the use of Pulse Width Modulated (PWM) command signals is increasing as it allows for partial positioning (eg. 50% open) of the intake manifold valves under certain conditions. The Vacuum Actuator uses a diaphragm and push rod to convert the vacuum into mechanical force, which acts upon a lever at the end of the Intake Valve Control Shaft.



The Mercedes Benz M272 V6 engine (2004 through 2012) is a good example, it uses two VSV's to control three actuators.

*Fault codes clear + precise to Intake control systems,
(via feedback system)
• voltage Drops*

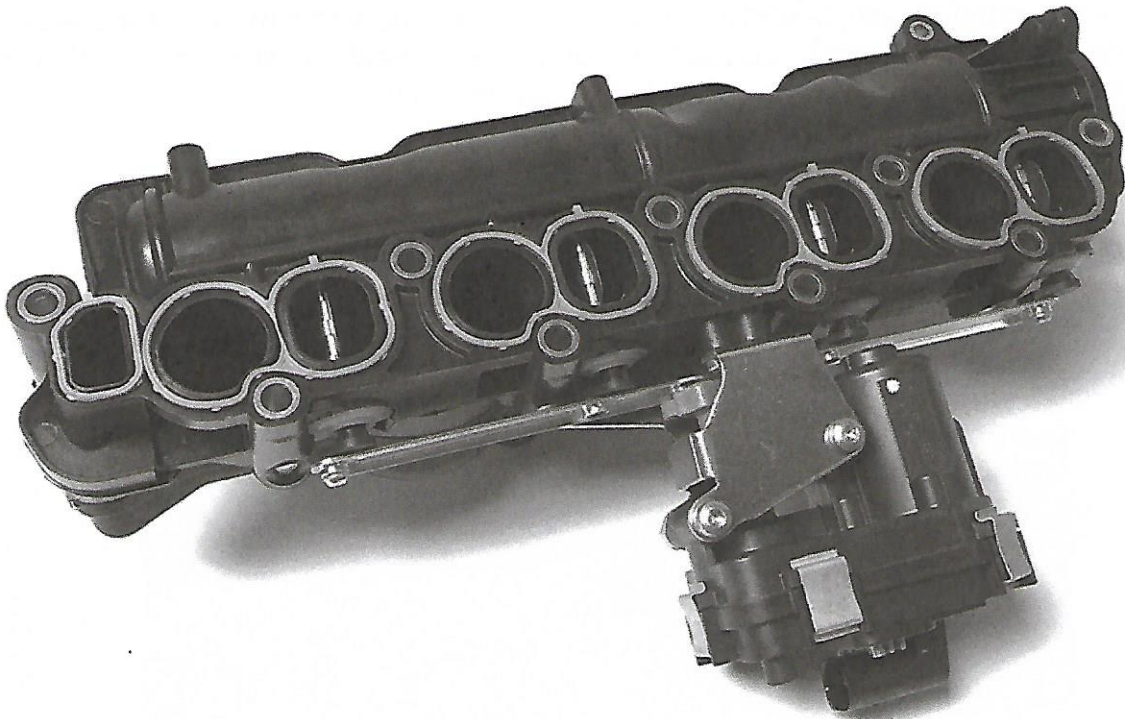
Best checked with scan tool Requested + Actual.

CONTROL SYSTEMS continued...

Electromechanical Actuator Systems

The electromechanical actuator is particularly good at allowing partial opening/closing of the intake control valves. It is also beneficial for overcoming issues with loss of vacuum either during full throttle operation or during high turbo boost.

The ECU uses PWM command to control the actuator, smooth transition between modes hides the changeover from the driver. The ECU usually monitors the current draw from the actuator to provide feedback.



*The electromechanical actuator, external linkages and swirl control valves
as found on the Saab 9-3 TiD 2007 to 2008
(the Holden Astra CDTi has the same engine but with an aluminium intake manifold)*

Repro sell replacements of these.

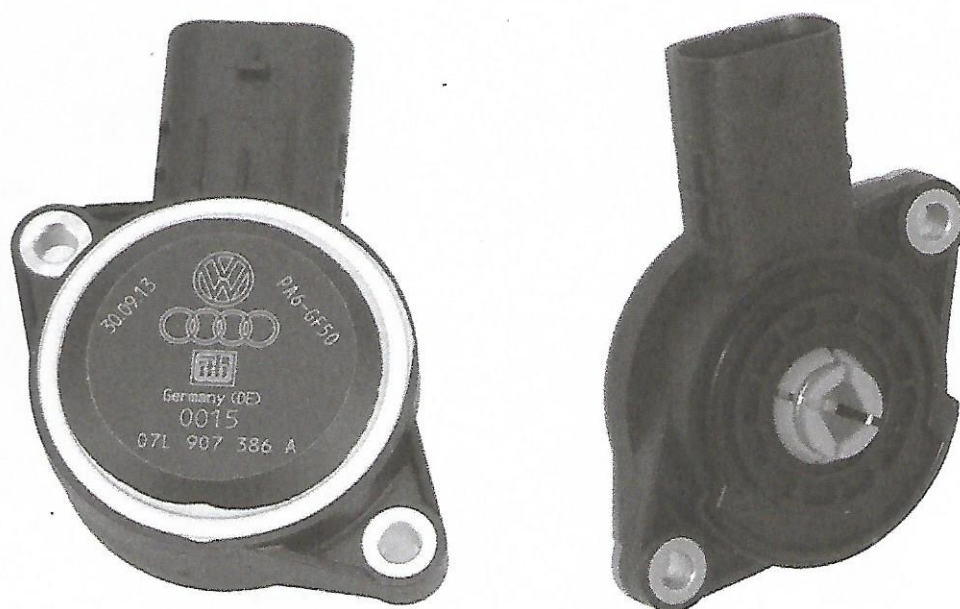
CONTROL SYSTEMS continued...

Electromechanical Actuator Feedback

Most vehicles employing an Electromechanical Actuator rely on feedback from the Actuator in the form of current draw for fault diagnosis. This system works reasonably well because it doesn't matter if the load on the actuator is due to carbon buildup or actuator fatigue it will log DTC's either way. It is up to the technician to diagnose the cause of the excessive load.

Intake Manifold Valve Position Sensor

A position sensor separates the sensor from the actuator which has one key advantage, if the sensor is located at the other end of the manifold to the actuator it is capable of detecting a lot more types of mechanical failures.



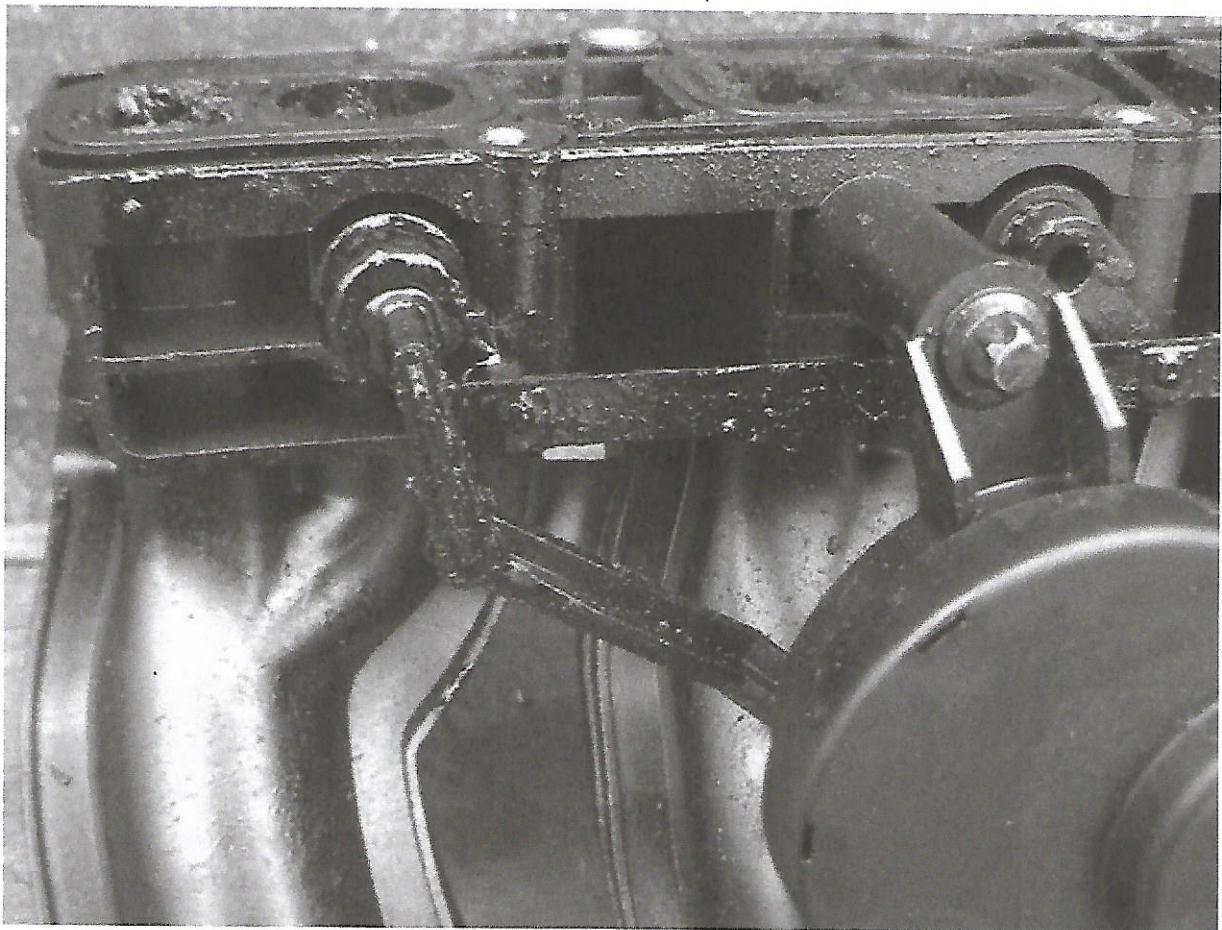
Intake Manifold Valve Position Sensors like these are found on most Volkswagen Group (VAG) vehicles

FAILURE TYPES

The Intake Manifold Swirl and Tumble Control Valves are usually located near the Cylinder Head. They are subjected to harsh pulses of air in both directions as the Intake Valves open and close. This puts considerable stress on the valves, mechanisms and actuators that control them.

Worn Manifold

It is not uncommon for the intake manifold control shaft to vibrate and wear the drilling's in the intake that it passes through.



On Diesel engines is it not uncommon to see oil building up around leaky shafts



Note:

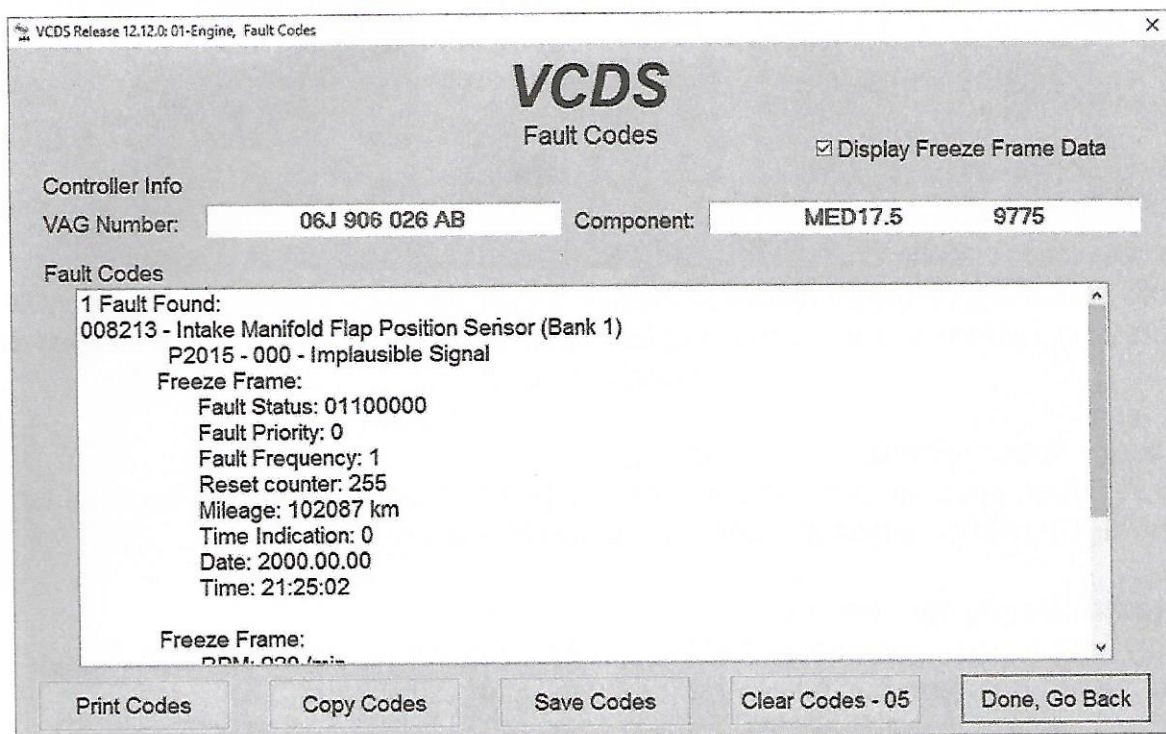
Worn manifolds rarely present in the workshop with Intake Manifold Control related DTC's!

If you can see the shaft end/s check for radial movement as the valves are opened and closed with the actuator. Apply the same procedure while pressurising the intake manifold with a diagnostic smoke machine and check for escaping smoke.

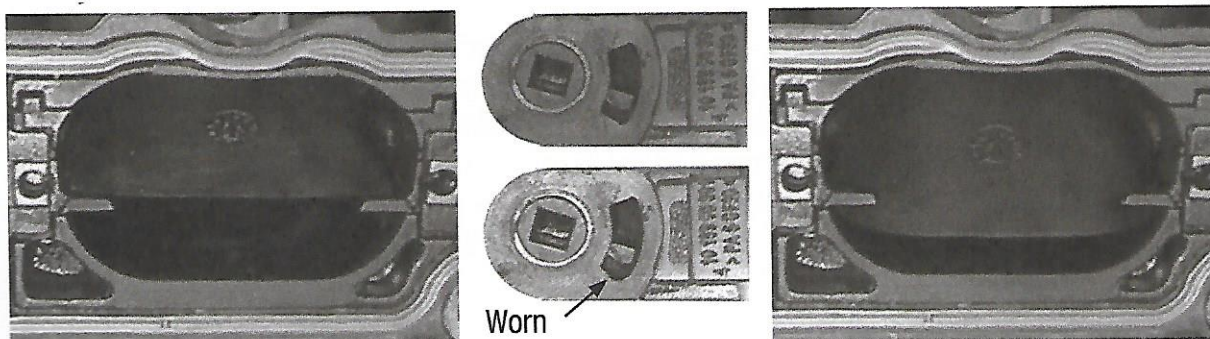
FAILURE TYPES continued...

Worn Shafts and Linkages

Vehicles using Position Sensors will often detect wear in the shafts and linkages, especially if the sensor is at the other end of the shaft to the actuator. The ECU will run correlation tests between the commanded position and the position signal registered at the sensor. These faults make up a vast majority of Intake Manifold Control related DTC's seen in workshops.



The P2015 DTC is an all too common sight across many VAG vehicles, if you see this code it is almost always due to wear in the shafts and linkages that allows the valves to move further than allowed.

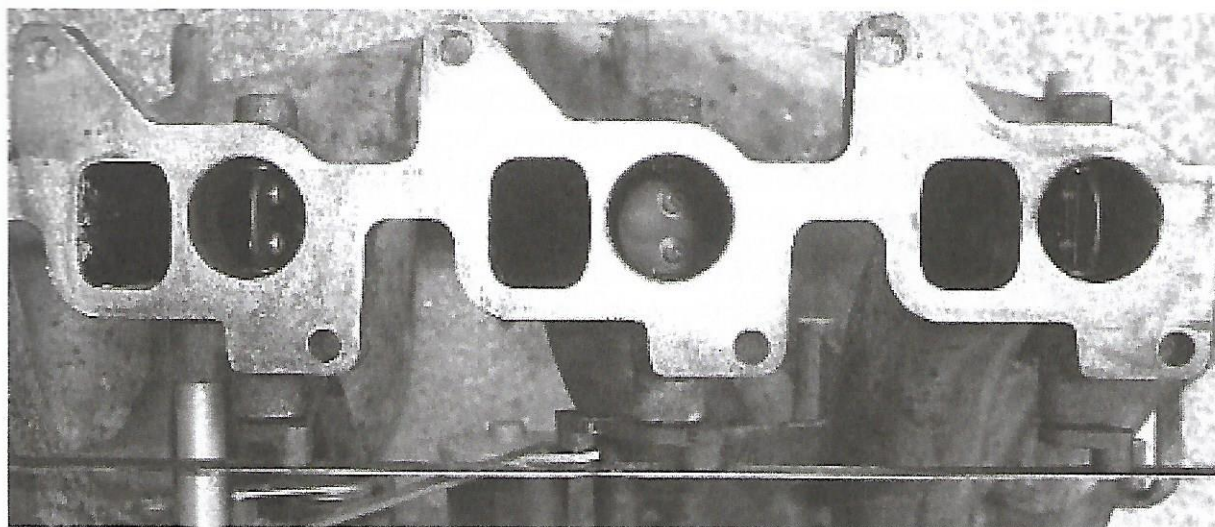


The image on the left shows the normal maximum closing position, while the picture on the right shows the overextended valve due to the worn stopper on the end of the shaft.



Note:

There is no need to dismantle the manifold for inspection, simply check that there is no freeplay, the valves fully retract and do not extend past the lugs!

FAILURE TYPES continued...

This Mercedes Benz Sprinter CDI has stripped the lever on the end of the valve shaft causing the valve on one channel to remain closed. This fault was not found until the manifold was removed for an unrelated repair.

Vacuum Supply Faults

For vehicles with a Vacuum Actuator, ensure that sufficient vacuum is available for control. There should be full manifold vacuum (43-56cmHg) at idle.

Actuator Diaphragm Failure

Apply $\approx 50\text{cmHg}$ of vacuum to the Vacuum Actuator with a Vacuum Pump. Check that the actuator arm has fully retracted by assisting it by hand.



Note:

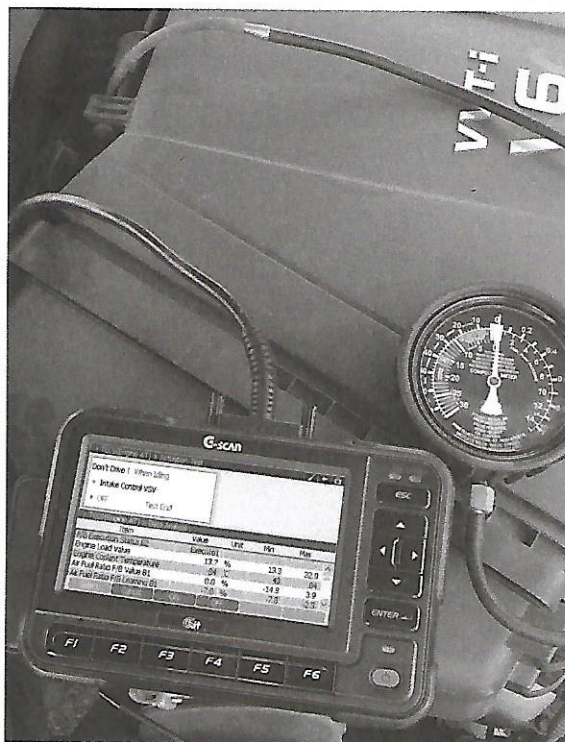
Some manufacturers may supply actuator distance specifications, use these if available!

Leave the Vacuum Pump attached and check that it holds a vacuum for at least five minutes.

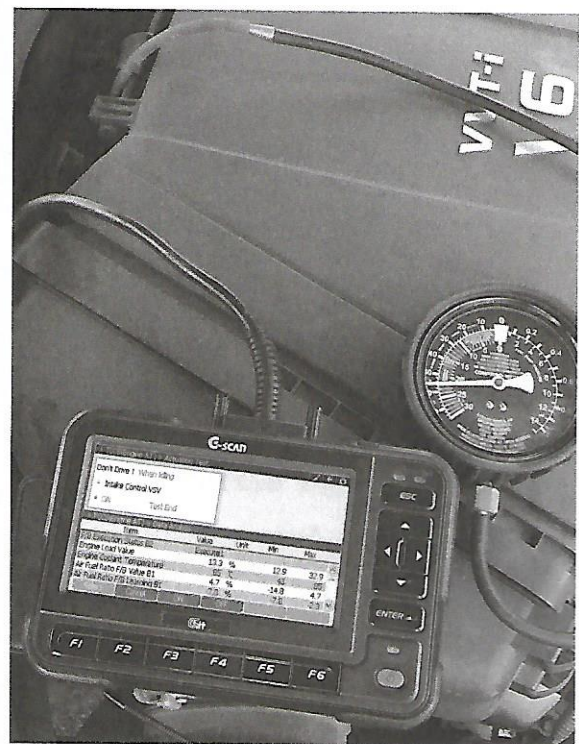
FAILURE TYPES continued...

Vacuum Switching Valve Solenoid Faults

If a VSV is controlled by a Battery Volts ON-OFF signal then it can be bench tested with a jumper battery, ensuring that air does not pass through in one condition and pass freely in the other. However, with many newer vehicles using PWM to control the VSV it is safest to use the Scan Tool Actuation feature to test its operation. Disconnect the vacuum hose from the actuator and connect to a gauge, follow the prompts on the Scan Tool and check for the corresponding change on the gauge. It is also important to check that the gauge falls quickly to zero when the command is OFF, a blocked vent will cause the vacuum to hold the actuator ON.



Command: OFF



Command: ON

Electromechanical Actuator Failure

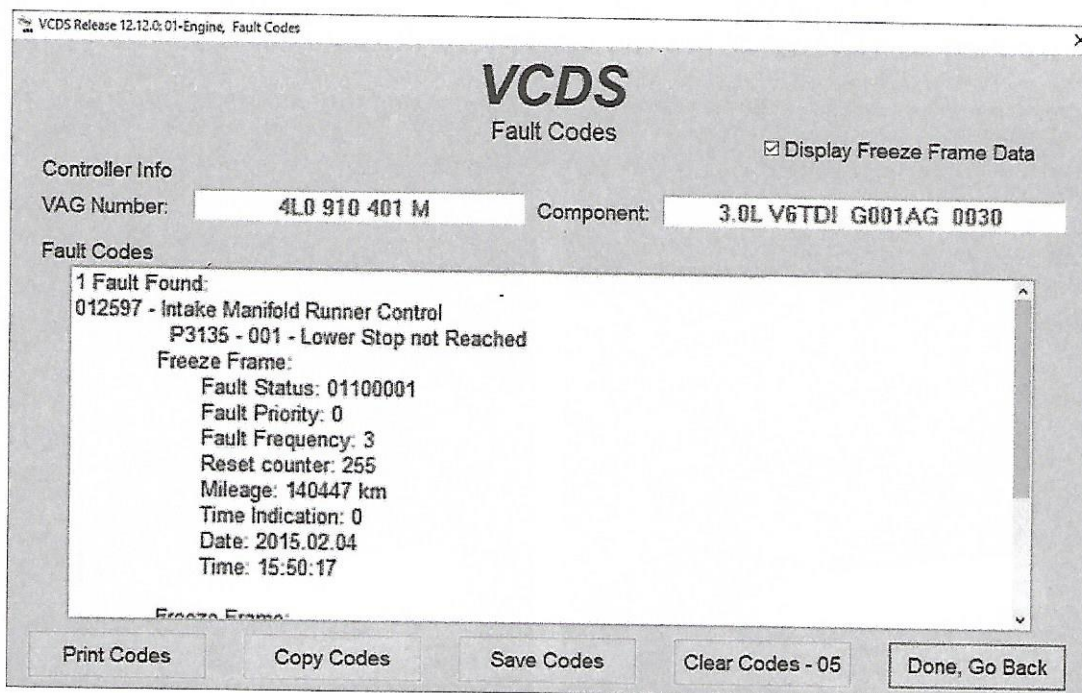
The best and easiest way to test Electromechanical Actuators is with a Scan Tool Actuation Test. It is usually possible to see the actuator rod moving (may need a mirror and torch). There are rarely specifications provided on actuator movement in distance, so comparison with a known good vehicle is one option. If the actuator provides feedback this value can be useful

FAILURE TYPES continued...

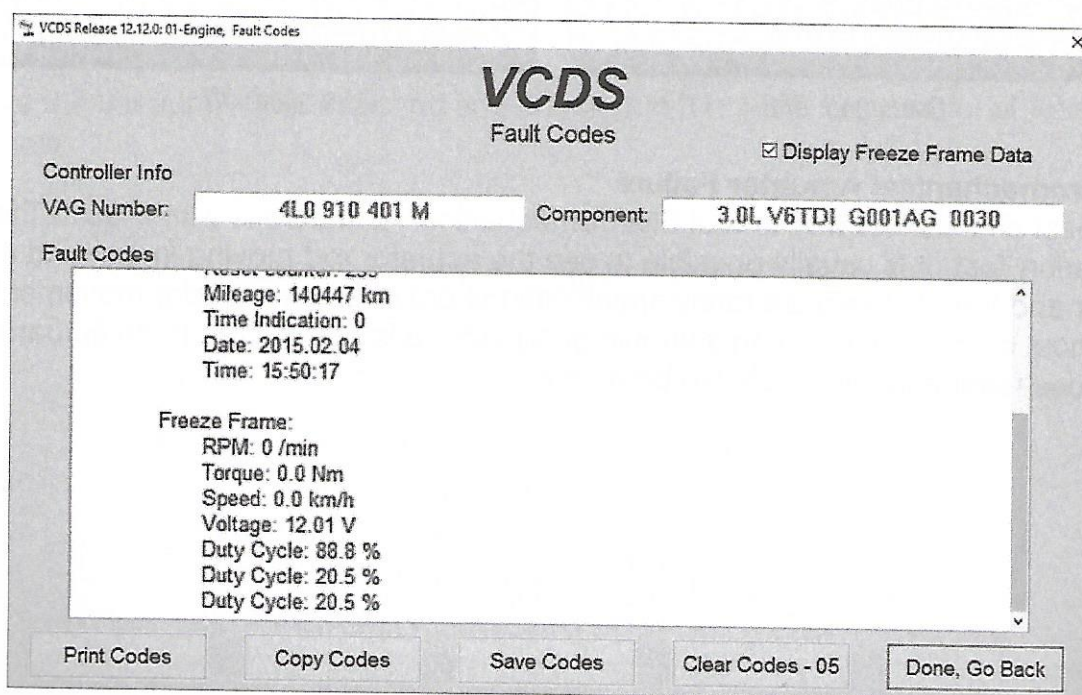
Audi Q7 3.0L V6 TDI with faulty electromechanical actuator

This example shows the VCDS Output Tests used to confirm a P3135 Intake Flap DTC. The freeze frame data showed that while the ECU commanded a $\approx 20\%$ duty cycle to open the valve, the position sensor continued to report $\approx 90\%$. This flagged the DTC for 2 reasons:

- Correlation
- Outside of the 20-80% Parameter



DTC P3135



Freeze Frame Data for DTC P3135

FAILURE TYPES continued...

This vehicle actually has 2 separate actuators (one for each bank) and the DTC description was clear as to which bank was at fault.

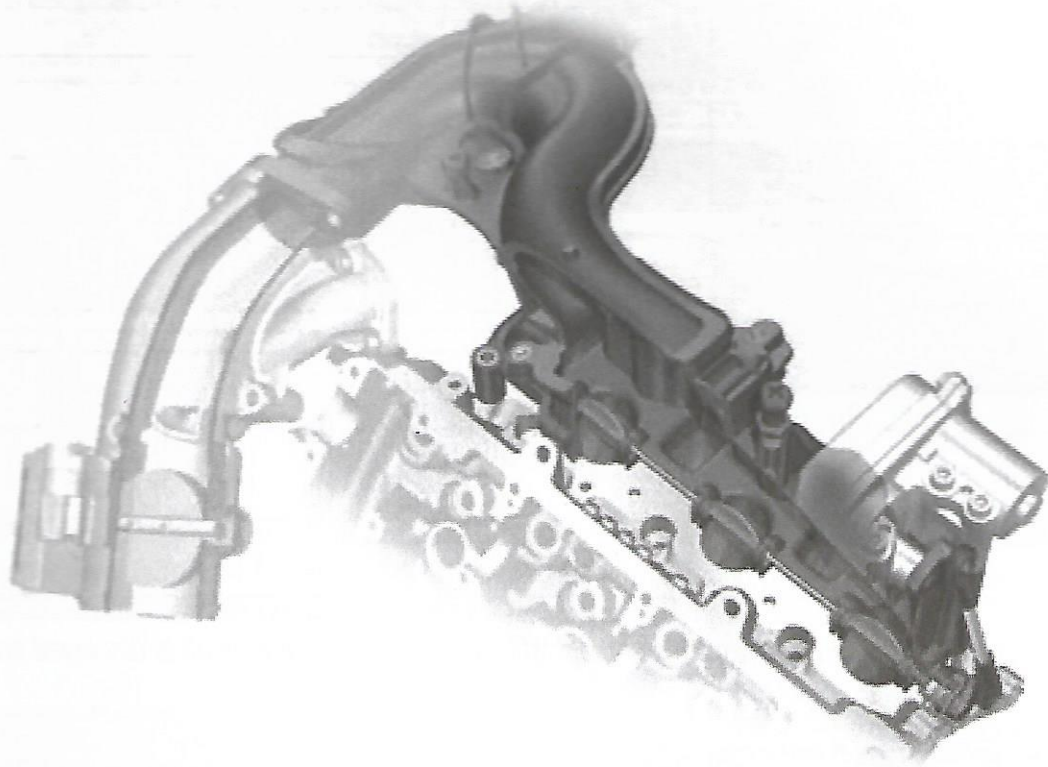


Illustration of the Bank 1 Intake Swirl Control System, Bank 1 is located on the Passenger Side with the actuator at the rear of the engine.

Solenoid testing
under 15amps circuits.

- amp clamp connected
- Voltage measured.
- Voltage line must not alter when solenoid is activated.
- this tells you that there is not excessive amp draw.
- Test is for only excessive current draw (about 80% problems)
not low current draw.

Output Test

The screenshot displays the VCDS (VAG COM Diagnostic System) software interface. A window titled "VCDS Release 14.10.1: 01-Engine, Output Tests" is active, showing a list of tests for "Intake Manifold Flap, Bank 2". The test "80.9 % Duty Cycle" is selected, and the "Activated output" is shown as a square wave. The "Next" button is highlighted. In the background, a waveform graph is visible, showing a square wave signal over time (0 to 500 ms). The graph has a vertical axis labeled "V" ranging from -16.0 to 14.0. The horizontal axis is labeled "ms" and ranges from 0 to 500. The graph shows a square wave signal that is high (around 10V) for most of the time and low (around -10V) for a short duration. The software interface includes a menu bar at the top with options like "File", "Edit", "View", "Tools", "Help", and "Window". A status bar at the bottom shows "Running" and "Trigger" buttons.

Both lower waveforms are for bank 2 and their ratio is similar. The same result is displayed on VCDS

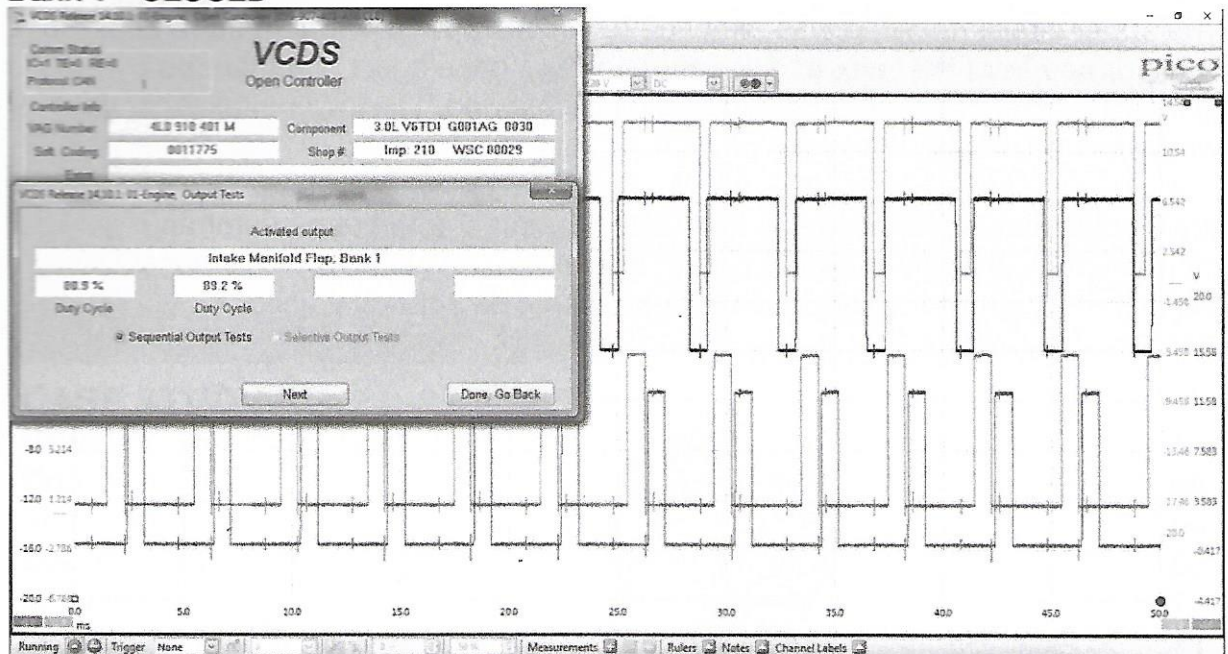
The screenshot displays the VCDS (VAG COM Diagnostic System) software interface. In the foreground, a window titled "VCDS Release 14.10.1: 01-Engine, Output Tests" is open. It shows the "Activated output" section with "Intake Manifold Flap: Bank 2" selected. Below this, there are two duty cycle settings: "20.5 %" and "20.9 %", both labeled "Duty Cycle". There are also radio buttons for "Sequential Output Tests" (selected) and "Selective Output Tests". At the bottom of this window are "Next" and "Done Go Back" buttons.

In the background, the main VCDS window is visible. It shows the "VCDS" logo and "Open Controller" button. Below this, there are fields for "VAG Number" (4L0 910 401 M), "Component" (3.0L V6TDI G001AG 0030), "Soft Coding" (0011775), and "Shop #". The "Extra" section is also visible. The main window displays a waveform graph with multiple channels, showing a series of pulses. The x-axis represents time in milliseconds (ms), ranging from 0 to 500. The y-axis represents voltage (V), ranging from -4.417 to 10.94. The graph shows a series of pulses, likely representing the output of the engine or a specific component.

Both lower waveforms are for bank 2 and their ratio is similar. The same result is displayed on VCDS

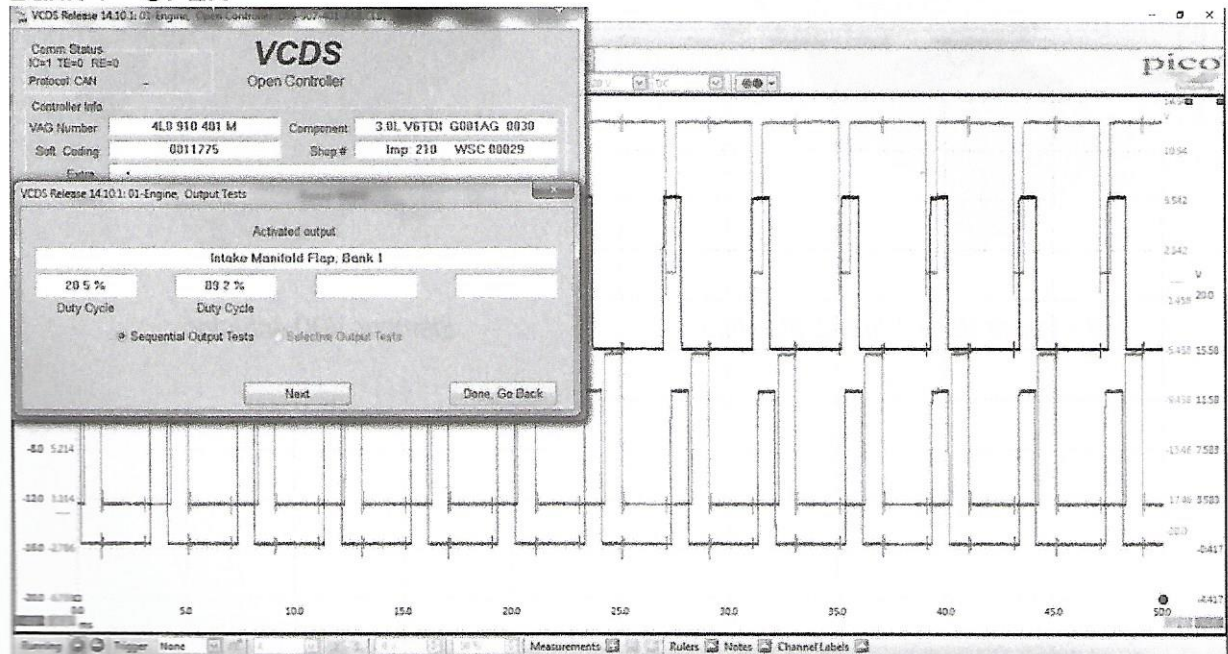
FAILURE TYPES continued...

Bank 1 - CLOSED



Both upper waveforms are for bank 1 and their ratio is similar. The VCDS does show a discrepancy of $\approx 10\%$ with the position sensor signal report $\approx 90\%$ when the limit is $\approx 80\%$

Bank 1 - OPEN



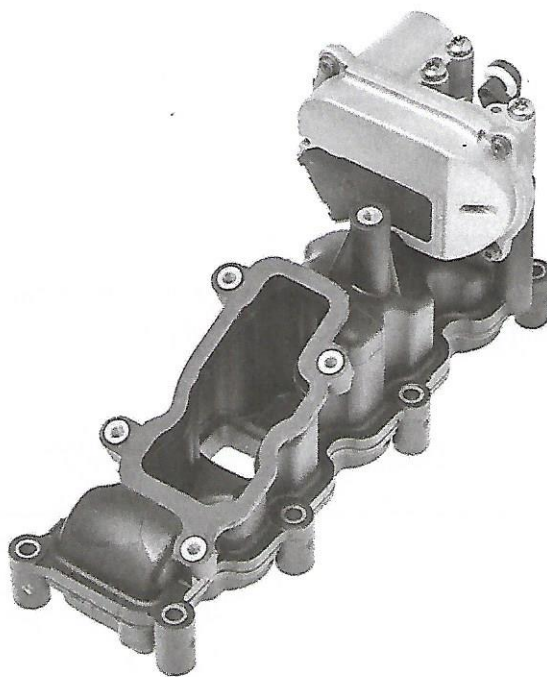
Both upper waveforms are for bank 1 and fault is now evident, while the command duty cycle has dropped to $\approx 20\%$ the position sensor signal is still reporting $\approx 90\%$.
The same result is displayed on VCDS

FAILURE TYPES continued...

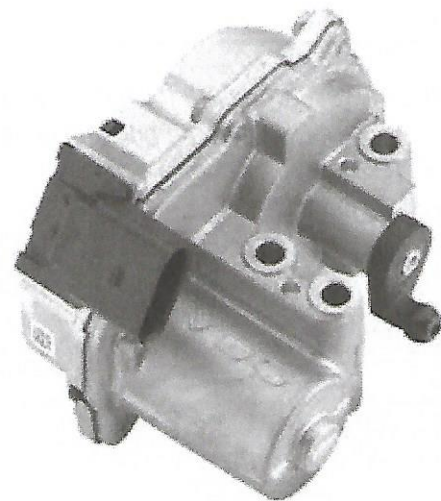
Fix

The upper intake manifold was removed to access the Bank 1 actuator, the ball joint was popped from the lever and the actuator was once again commanded by the VCDS. This showed that the actuator did not respond. The lower intake manifold was removed and had no signs of wear.

VAG states that the lower manifold must be replaced with the actuator and therefore they are only available as a pair from Audi/VW. However SiemensVDO make the actuator for VAG and sell the actuators as individual units.



VW - Lower Bank 1 Intake Manifold



Siemens VDO Actuator

Section iv**CAN Bus - Part 2****CONTENTS**

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CASE STUDY #1

In Masterclass 2017.1 we covered the Introduction to Diagnosis which focused on Network Topology, CAN message processes and diagnostic approaches. This training manual will cover a practical application of those principles.

Vehicle

2013 Toyota GSU45R Kluger KX-S, 2GR-FE engine, Auto, AWD

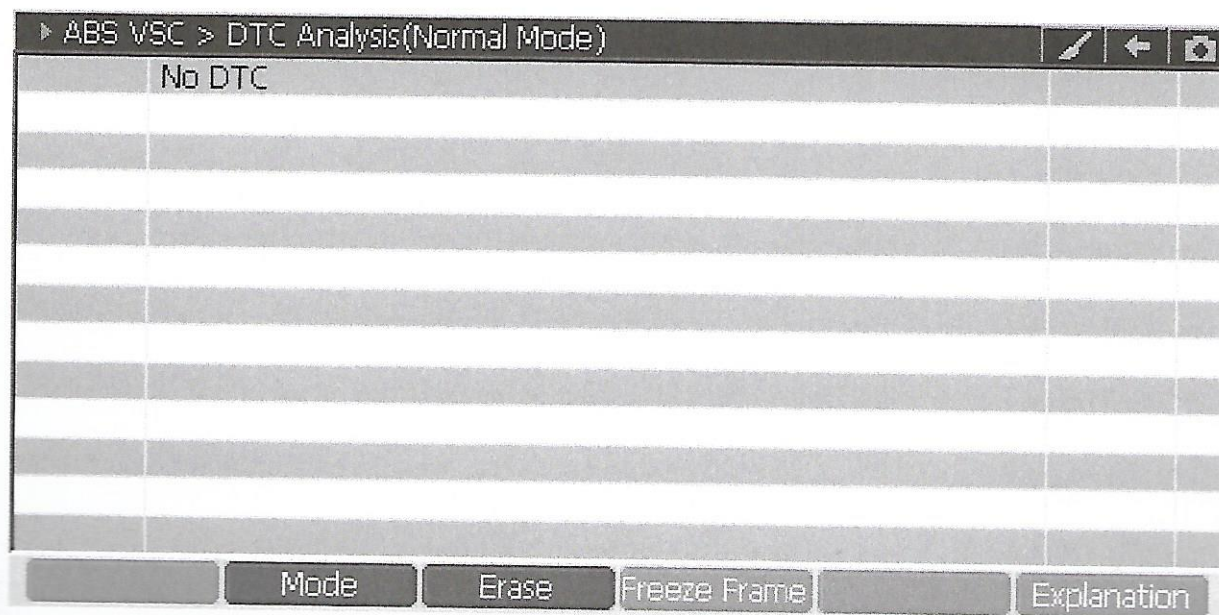


Complaint

Vehicle intermittently displays a variety of fault messages about the brakes on the Multi-information Display. At the time of arrival the fault was not evident, all messages had cleared. Owner stated that the fault would sometimes occur on the road and other times it would be there from startup. Vehicle was left with the workshop for a service and further diagnosis.

Initial Inspection

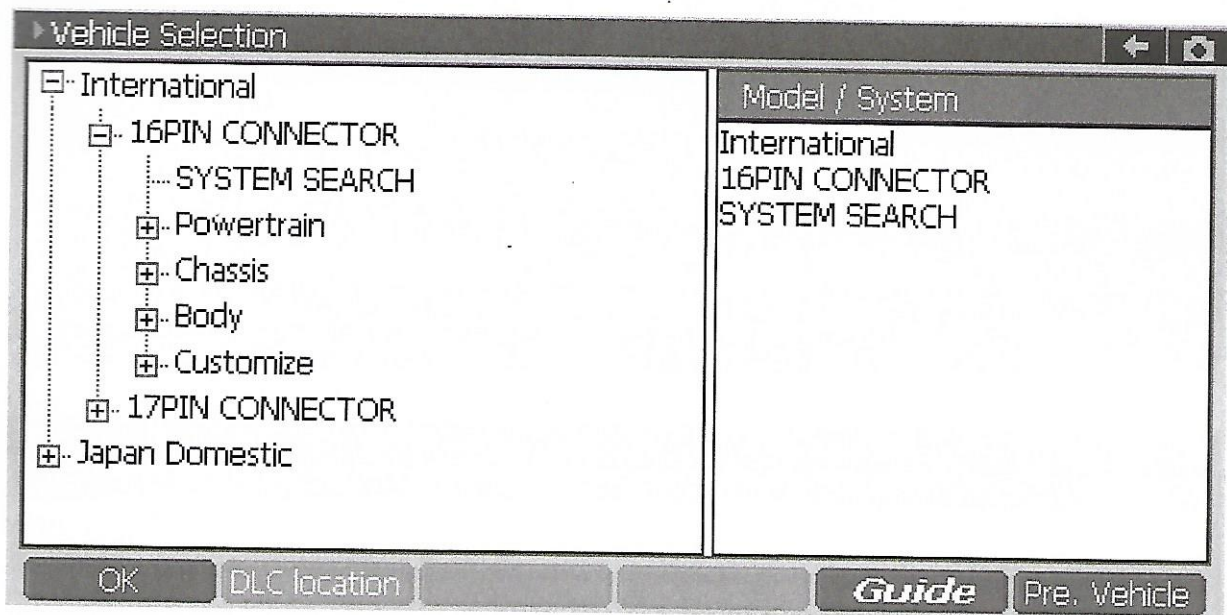
On any vehicle it is beneficial to get to know the vehicle. Look for anything that rings alarm bells and check the DTC's. As the complaint stated brake related warnings the first DTC check was the ABS/VSC Module. No DTC's there...



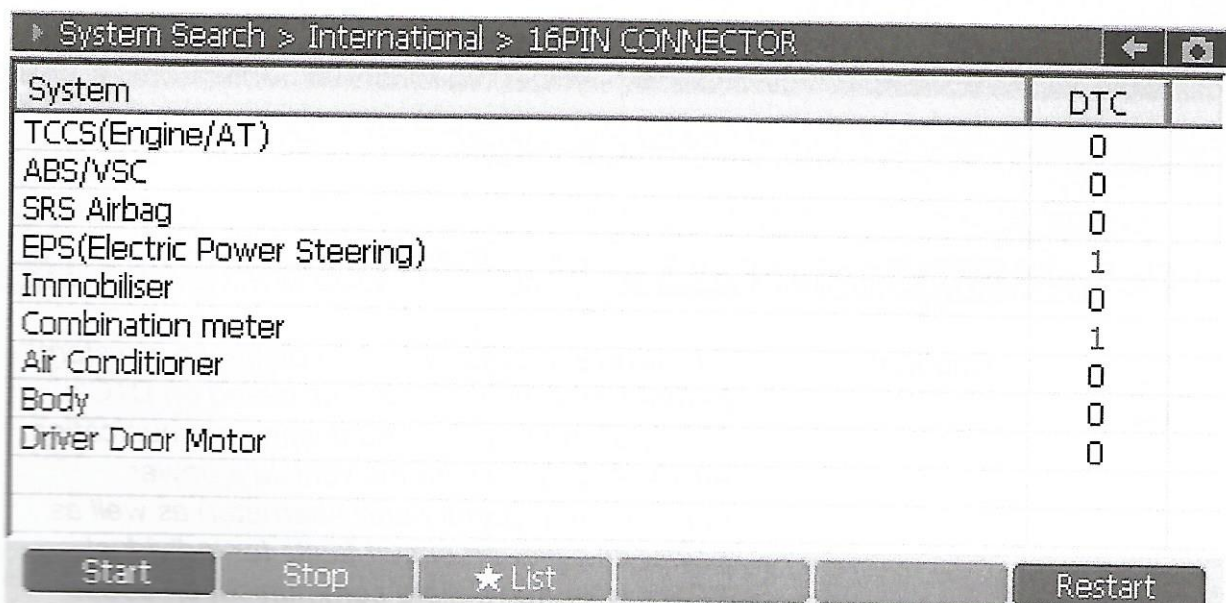
CASE STUDY #1 continued...

Detailed Inspection

Next check was a full vehicle scan. When this procedure is activated the Scan Tool will send out messages (called polling or pinging) onto the CAN Bus and wait for responses. Once communication has been established it will usually build a list of all of the Nodes it has made communication with and the number of DTC's stored in each ECU (if any). Some Scan Tools automatically poll all modules and codes as soon as the vehicle has been selected while others need to be initiated and some do not poll at all and each module must be communicated independently.



The G-Scan does not automatically poll the individual ECU's, but it can be initiated by selecting the SYSTEM SEARCH



The Scan Tool collects a list of ECU's that it has made contact with and the number of DTC's stored in each module.

CASE STUDY #1 continued...

A DTC investigation of both ECU's with logged codes found that they both contained the same history DTC U0129...

► Combination meter > DTC Analysis

DTC	Description	History
U0129	Lost Communication with Brake System Control Module	

Mode Erase Freeze Frame Explanation

► EPS(Electric Power Steering) > DTC Analysis(Normal Mode)

DTC Code	Description	History
U0129	Lost Communication with Brake System Control Module	

Mode Erase Freeze Frame Explanation



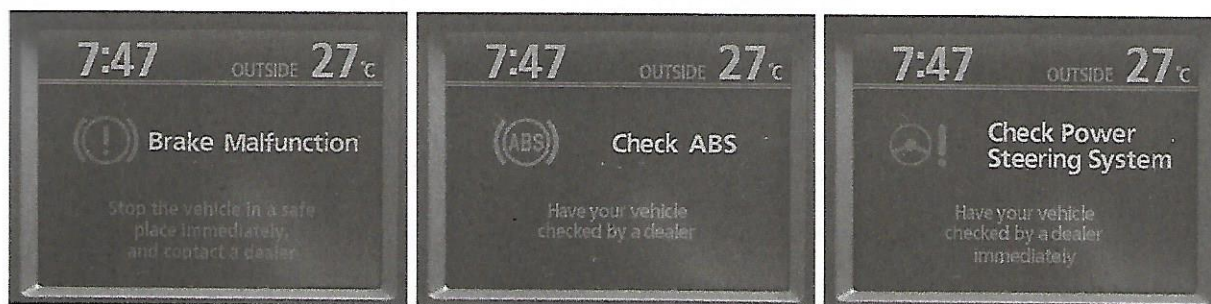
Caution:

It is always necessary to fully diagnose a system before replacing components based on DTC's. This is even more important with communication errors. Any faults with the vehicle's power management (Battery and Alternator) as well as power and ground circuit faults for individual ECU's will often initiate communication codes (Uxxxx). One indicator of this is when the codes have been moved to History status.

CASE STUDY #1 continued...

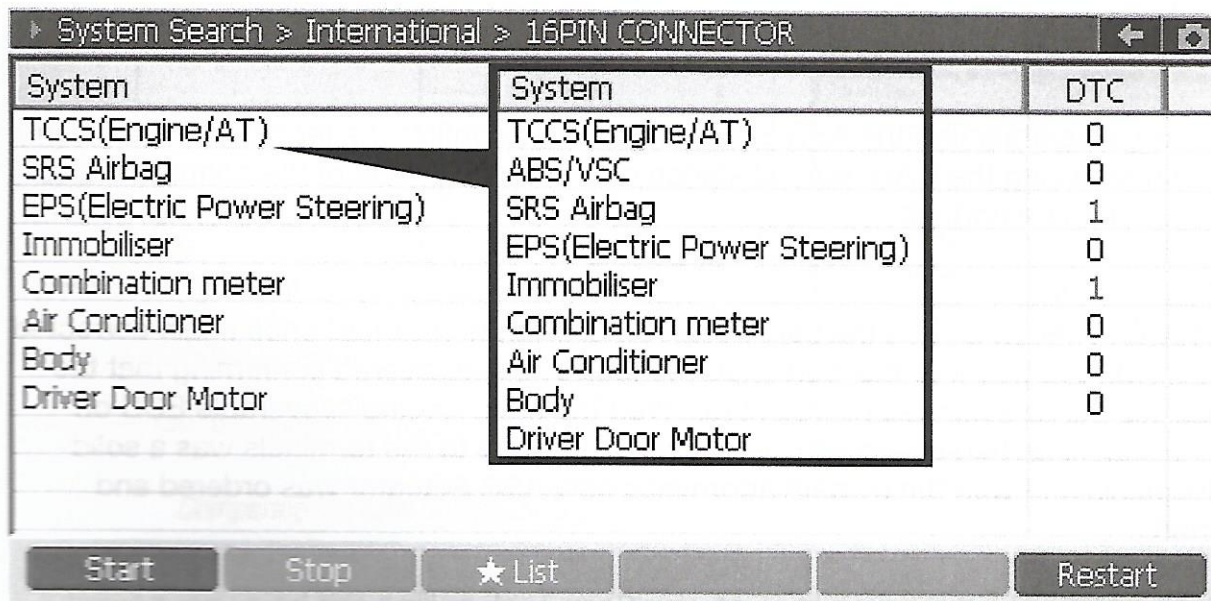
With nothing else to go on the Battery Terminals were checked for voltage drop, as were the power and ground circuits of the ABS/VSC Modulator. All tested at less than 100mV. The Alternator was also checked and deemed serviceable. With very little proof of the fault and with the intermittent issue currently behaving itself the owner of the vehicle authorised an extended road test. This was done over the course of three days with the workshop owner/technician using the vehicle for his 30 minute commute to and from work.

On the morning of day three the fault occurred...



Wanting if at all possible to diagnose the fault while it was present had one small hiccup, only the Scan Tool, a multimeter and a few basic hand tools were available. All of the other tools and equipment including the oscilloscope were at the workshop.

Carrying out a system search immediately identified two changes over the diagnostics that were carried out a few days prior; The two DTC's were now logged as both current and history, indicating that the fault was currently occurring. But most importantly from a diagnostic point-of-view the ABS/VSC module had dropped off list!



The insert shows the last time a search was carried out the ABS/VSC ECU was online.

CASE STUDY #1 continued...

This was what was needed, a confirmation that a communication fault actually does exist. This was about as far as we could go with the Scan Tool on this vehicle, as the ECU could not be communicated with. With the fault in its current condition the cover was removed from the ABS ECU Connector and the CAN Bus resistance was measured and found to be within specifications.



Toyota's specification for resistance on the branches of the CAN Bus is 59-70Ω

Next step was to confirm that the ABS ECU was getting power and ground, along with a wiggle test to try force an error. All circuits passed. To confirm that the fault hadn't corrected itself during diagnosis the SYSTEM SEARCH was restarted and the ABS/VDC was still undiscoverable.

Finally, disconnecting the ABS ECU connector to confirm the terminals were clean and rechecking the CAN Bus resistance on the terminal side of the connector also found all to be normal.

Conclusion

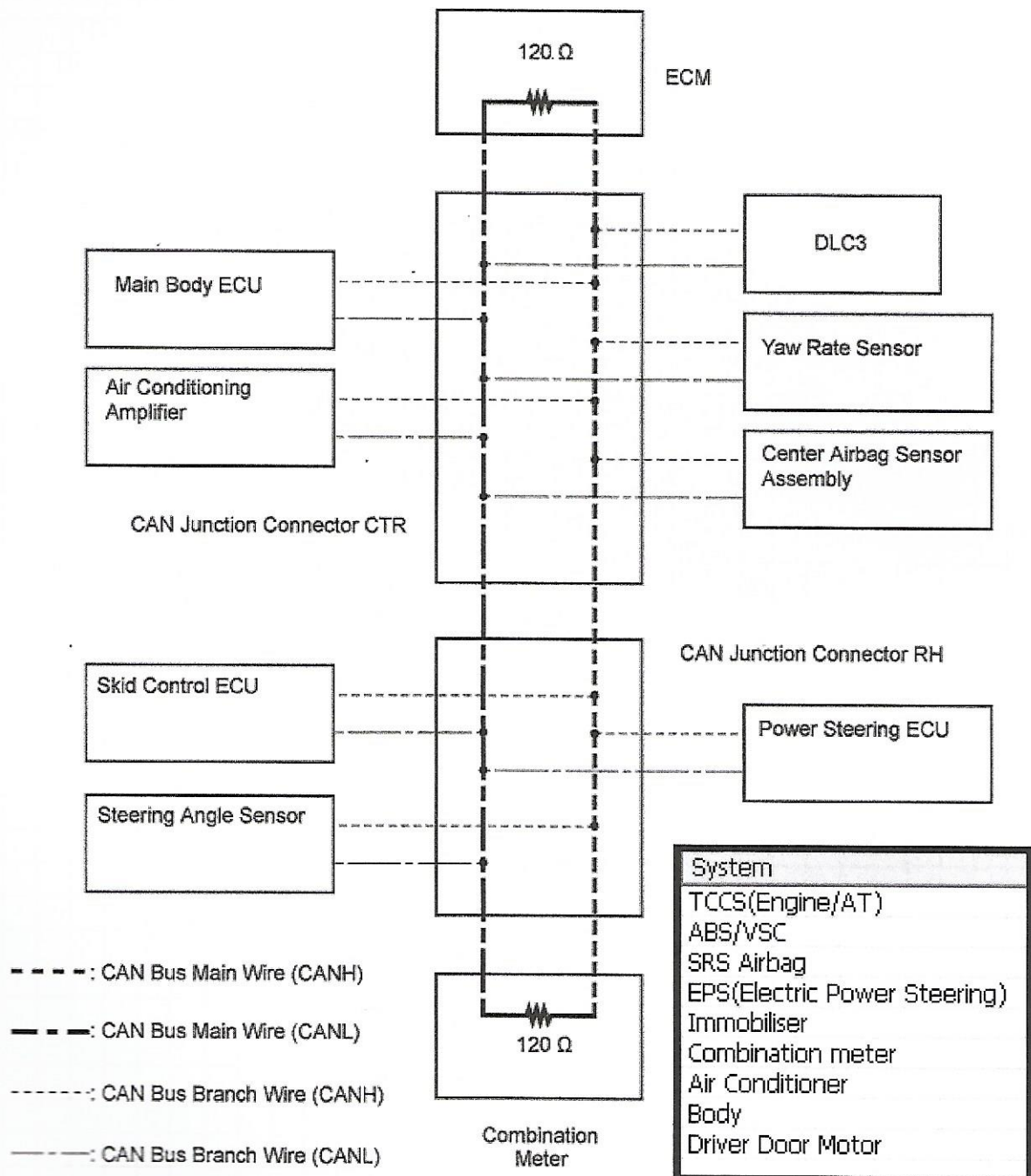
Of course reconnecting the connector found that the fault had once again corrected itself. On the way into the workshop the fault briefly appeared confirming that the playing with the connector hadn't resolved the fault. An undiscoverable ECU on a network that had tested as operational all the way to the terminals was a solid diagnosis and with the owners approval a new ABS Actuator was ordered and fitted.

Dependant upon the capabilities of your Scan Tool, polling can be a very powerful tool for diagnosis. The following are a few examples of different Scan Tools and their capabilities.

CASE STUDY #1 continued...

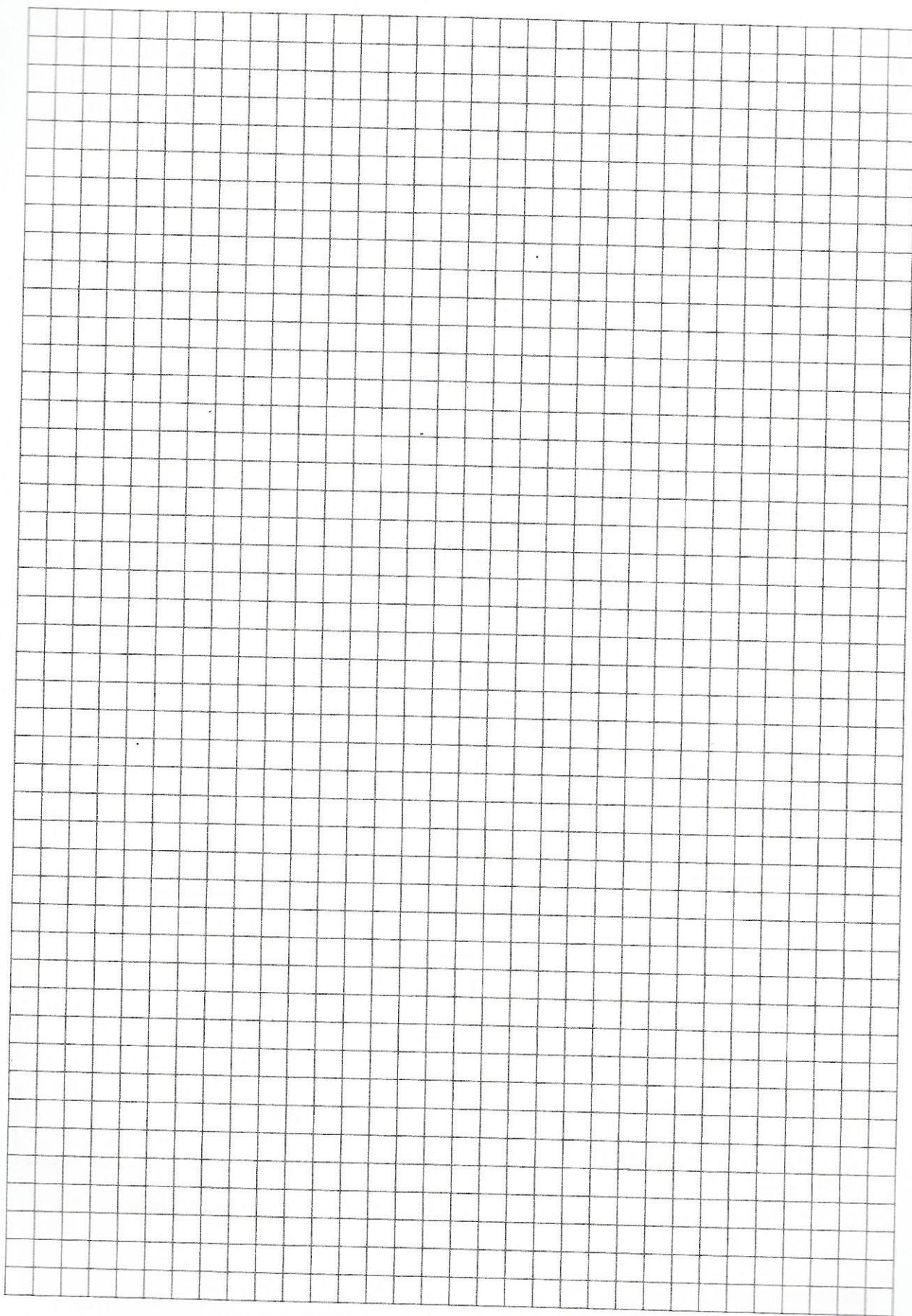
G-Scan (and G-Scan2)

The G-Scan tools offer the SYSTEM SEARCH feature that was used in the case study. It sends out pings and builds a list from the nodes that respond. Because the Scan Tool doesn't know which ECU's are on the Bus it cannot flag when one is offline. The technician will need to refer to the repair manual to find out which ECU's should be online.



Comparing the CAN Schematic against the ECU list is a good starting point

NOTES



CASE STUDY #2

VCDS

The PC based VCDS offers an Auto-Scan feature for all CAN Bus Volkswagen Group (VAG) vehicles that is a little more comprehensive. The Scan Tool first makes communication with the CAN Gateway module which contains a list of all of the ECU's on the CAN Bus. It then pings each module for communication check followed by a status request:

- 0010 means there are DTC's stored in the ECU
- 1100 means that the CAN Gateway has the ECU in the list of installed ECU's but it is unable to communicate with the module.

Vehicle

2010 Volkswagen Golf Mk.6 103TDI, CFFB engine, 6 spd DSG



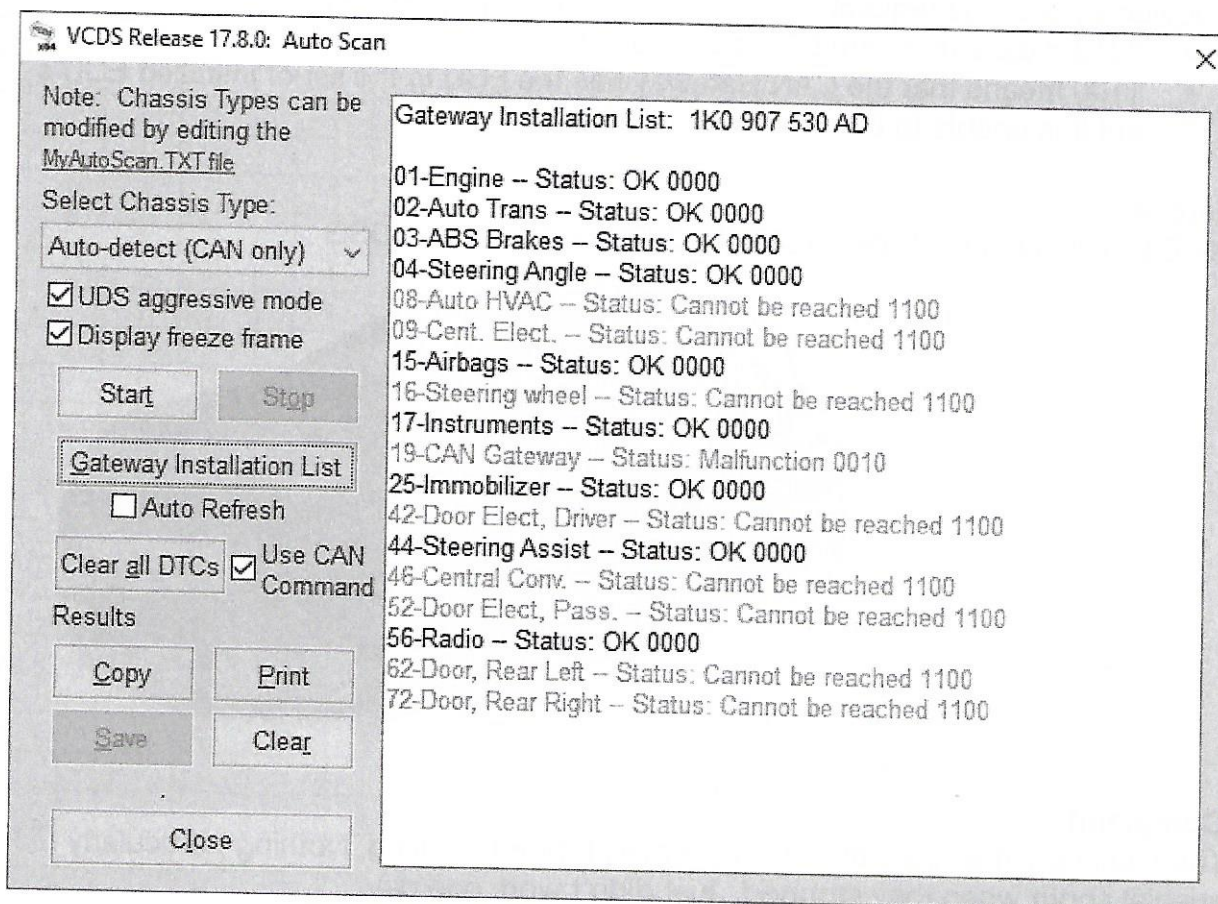
Complaint

The steering wheel controls and A/C have stopped working. Nothing particularly special about when they stopped. Just didn't work one day.

CASE STUDY #2 continued...

Initial Inspection

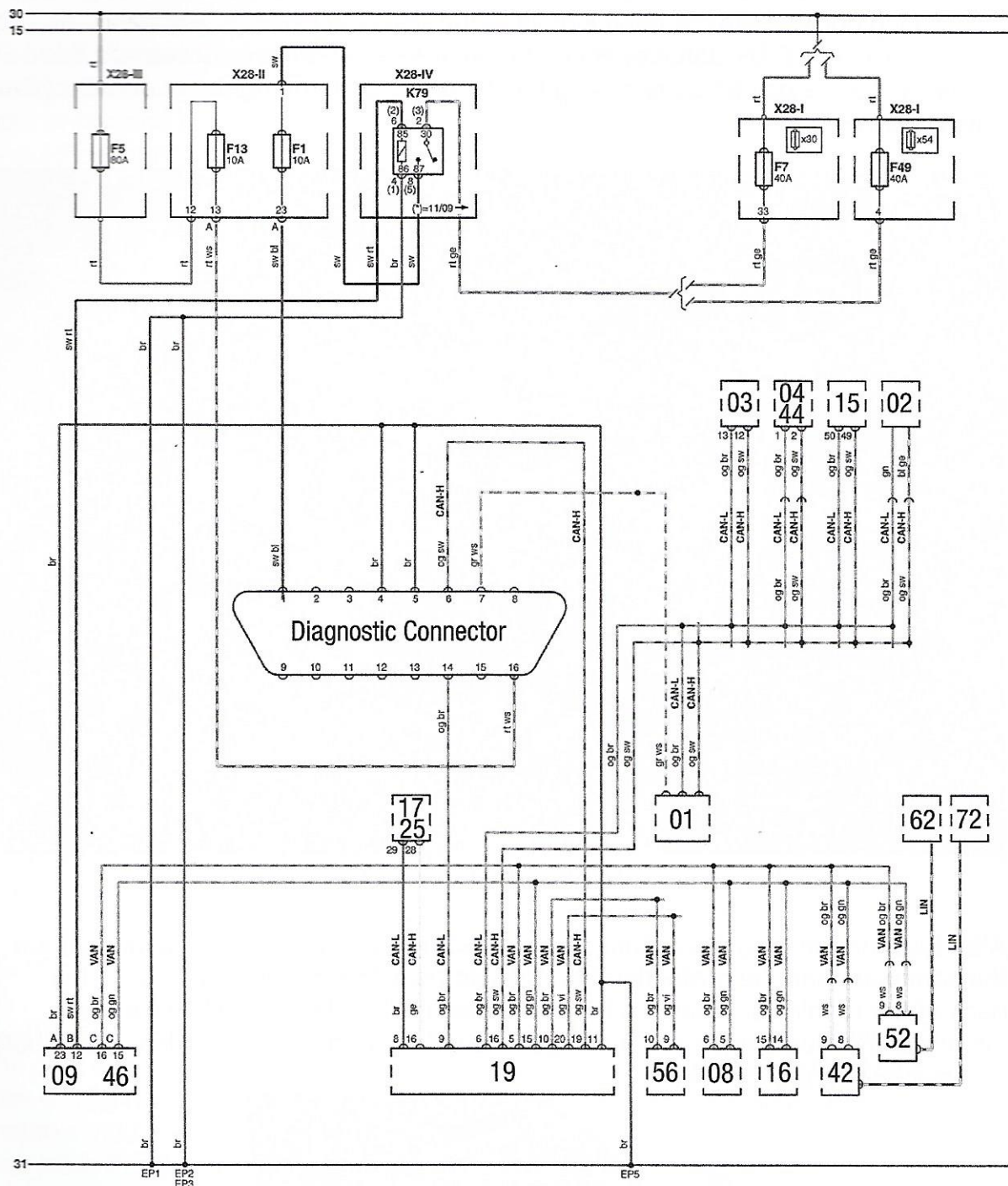
On any vehicle it is beneficial to get to know the vehicle. Look for anything that rings alarm bells and check the DTC's. The Auto-Scan feature of VCDS is the easiest way of scanning for codes in all modules at once. The following results were found:



Detailed Inspection

Looking at the Auto-Scan results we can see that the CAN Gateway has reported back that DTC's are stored. There are also a variety of other ECU's that have not responded to the ping. The next step is to interrogate the CAN Schematic for the relationship between these modules.

CASE STUDY #2 continued...



*CAN Schematic from Autopedia, edited to only show relevant ECU's (for clarity)
with the VAG module group codes added for relevance to VCDS.*

The CAN Schematic shows that all of the affected ECU's are on a single network, referred to as Vehicle Area Network (VAN) connected to Pins #5 & 15 of the CAN Diagnostic module (19).

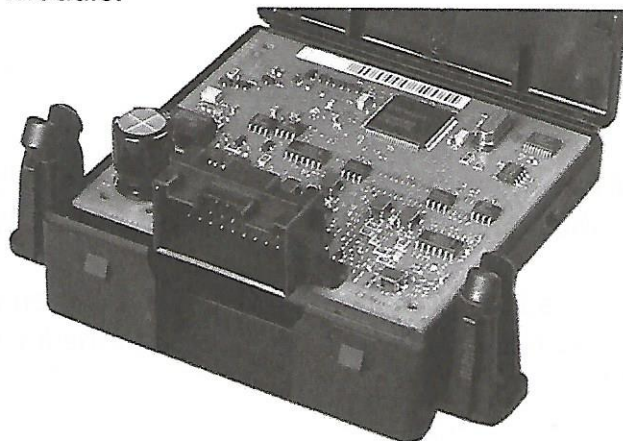
CASE STUDY #2 continued...

VCDS tells us that the VAN operates under the CAN Protocol so even though the terminating nodes have not been identified there should be $\approx 60\Omega$ resistance across the network. The CAN Gateway is one of the easiest modules to access on this model, access is gained by removing the wiper motor in the right rear corner of the engine bay.



Golf Mk.6 CAN Gateway location

After locating the ECU it was found that it was not a simple process to backprobe the connector and the protective cover would need to be broken to access the back of the terminals. When the ECU was disconnected from the vehicle the technician noticed some water had dribbled out. Upending the ECU led to a dribble of water exiting the module.

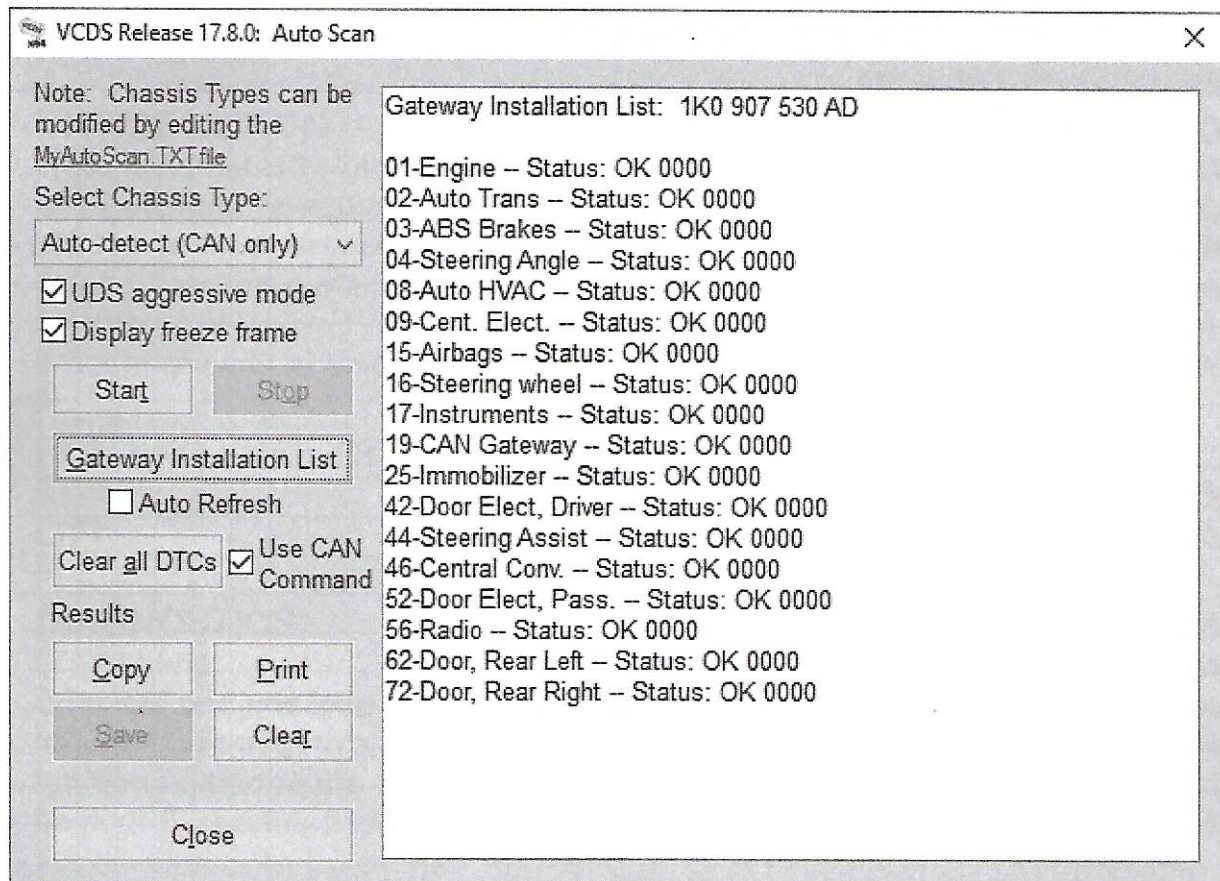


The housing of the CAN Gateway is clipped together and easily opened

CASE STUDY #2 continued...

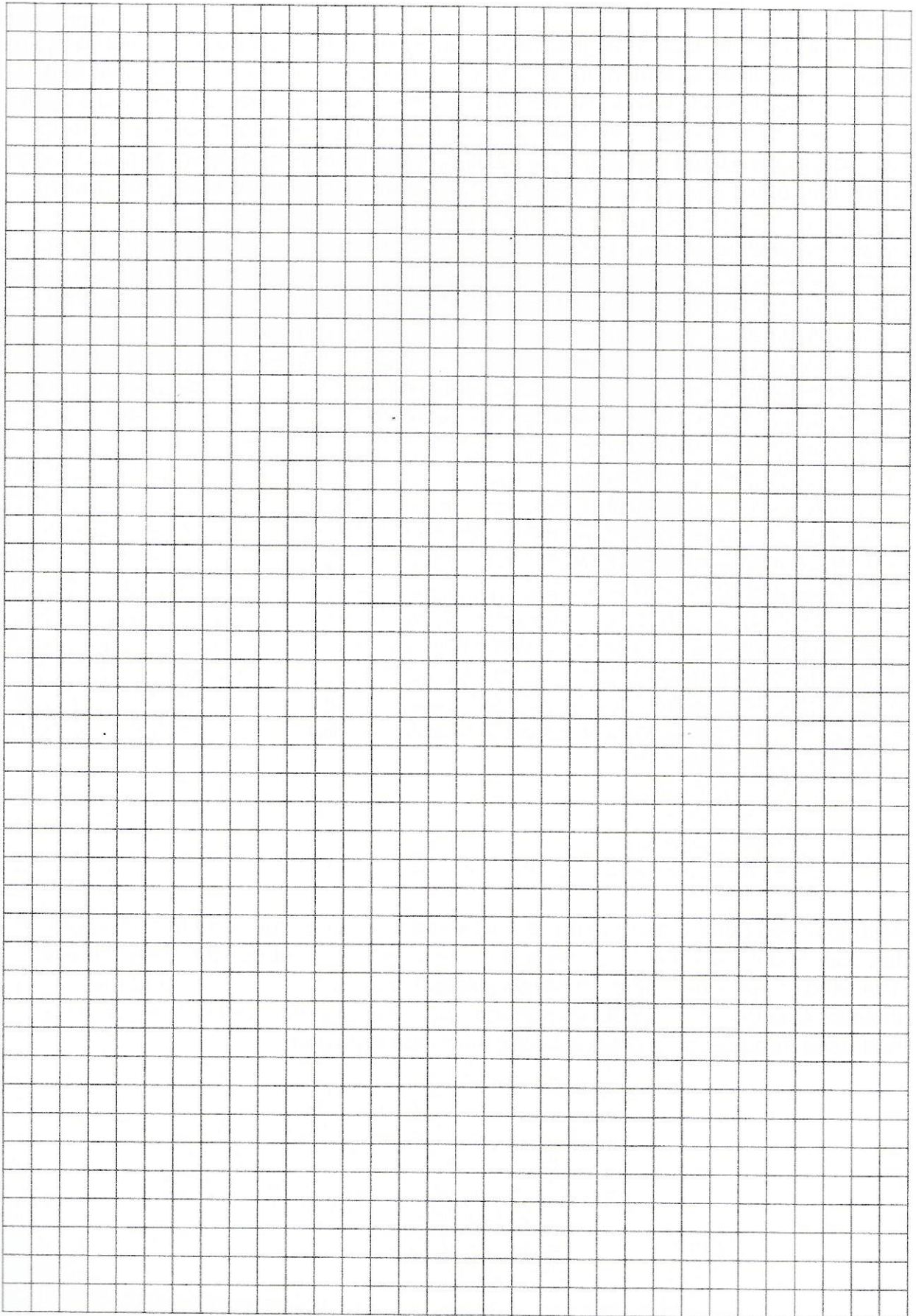
Repair

The CAN Gateway ECU was given a light spray with electrical contact cleaner to disperse the water and then blown dry with a hair dryer on warm setting (not hot) to dry off completely. It was reinstalled and the codes were cleared. All ECU's were now online and no codes returned. The vehicle owner was informed that the repair should be considered as temporary (as it is possible that corrosion may be an issue in the future) but as long as it keeps working there was no need to replace the unit.



Further investigation found that the windscreen had been replaced at some point in the past and it wasn't sealed properly in the area directly above the CAN Gateway. The windscreen was refitted (for this vehicle this meant a new glass) and the installer said the original sealant had not been properly removed before the glass had been fitted causing small air gaps along the right side.

NOTES

A large rectangular area filled with a fine grid of squares, intended for handwritten notes. The grid is approximately 30 squares wide and 40 squares high.

Section v**Diagnostics with Fuel Trims****CONTENTS**

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INTRODUCTION

What is a Fuel Trim Table

The ECU uses feedback from the Upstream Oxygen Sensor/s (UO₂S) to create a filter called the Short Term Fuel Trim (STFT) that is applied to the Base Fuel Map. If the STFT has a longterm trend the ECU will commit this value to another filter called the Long Term Fuel Trim (LTFT).

For vehicles with two bank control (they have two UO₂S) there will be:

- STFT-B1 (Bank#1)
- LTFT-B1 (Bank#1)
- STFT-B2 (Bank#2)
- LTFT-B2 (Bank#2)

The ECU will apply the Fuel Trim Tables in the following order:

$$\text{Primary Fuel Map} \pm \text{LTFT} \pm \text{STFT} = \text{Fuel Injection Quantity}$$

STFT order of operations:

1. Provide the ECU with the most accurate fuel map possible
2. The STFT is the direct result of the UO₂S
3. If the STFT is at zero, then there is currently no correction required over and above the LTFT



Note:

The STFT is only applied during closed loop control!

LTFT order of operations:

1. Record the average fuel trim characteristics from the STFT and apply them to the base fuel map. This means that if a vehicle has a constant error the LTFT will compensate and the STFT will be close to zero
2. If the LTFT is at zero, then there is no long-term correction required over and above the base fuel map (factory specification)



Note:

The LTFT is applied during open and closed loop control!

Open Loop Parameters

The STFT will have no effect on the fuel delivery during open loop control as the UO₂S/s are being ignored. Typical open loop conditions:

- Engine cold
- Heavy acceleration enrichment
- Wide open throttle
- Closed throttle deceleration
- Limp mode

Open/Closed Loop status is usually available in the Scan Tool Data.

INTRODUCTION continued...

Adaptive Limit

Once the combined value of the LTFT and the STFT exceeds the adaptive limit (threshold) it will log a DTC and illuminate the Malfunction Indicator Lamp. Generally the combined adaptive limit is between 30% to 50%.

Remember that this is combined:

- LTFT 30% + STFT 20% = 50% combined (MIL ON)
- LTFT 5% + STFT 45% = 50% combined (MIL ON)
- LTFT 25% + STFT -25% = 0% combined (MIL OFF)

What might a Fuel Map look like?

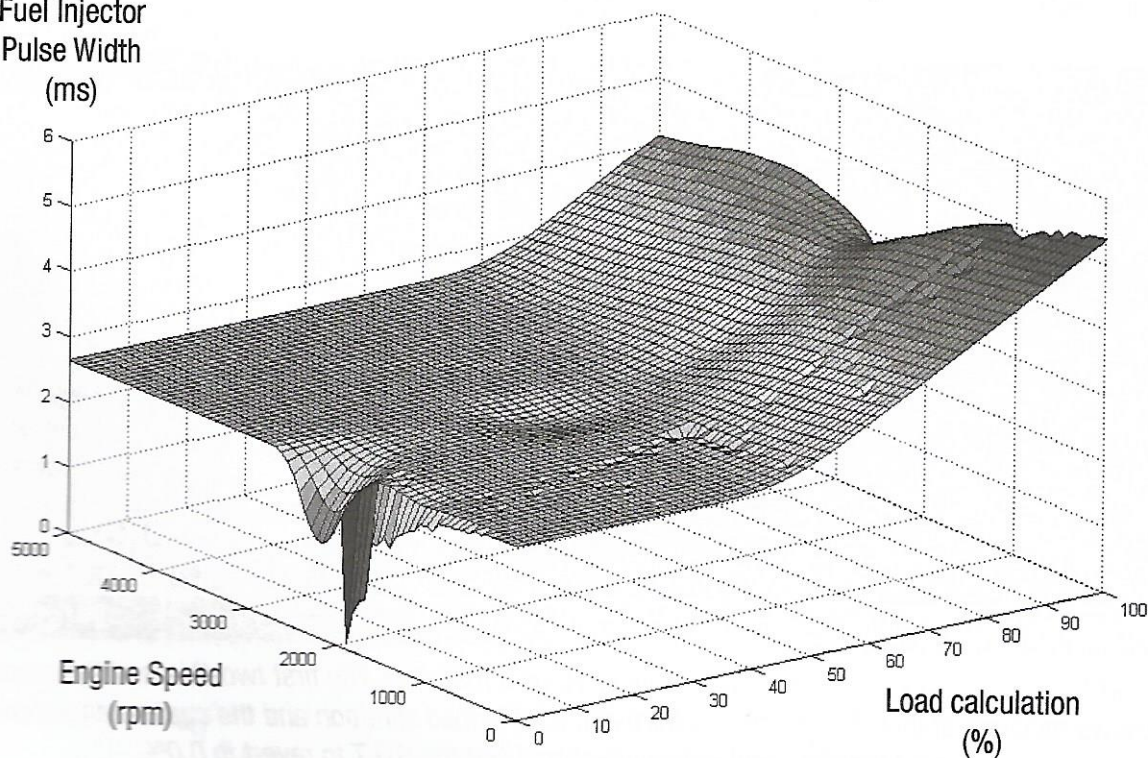
Early 1990's ECU's employed a 16 Cell Block Learn Fuel Map, this means that there are a total of 16 parameter combinations (0-15), with the load value often made up of only MAP and TPS inputs.

LOAD	0-800 RPM	800-1100 RPM	1100-1500 RPM	> 1500 RPM
1-25%	Cell 0	Cell 1	Cell 2	Cell 3
26-50%	Cell 4	Cell 5	Cell 6	Cell 7
51-75%	Cell 8	Cell 9	Cell 10	Cell 11
76-100%	Cell 12	Cell 13	Cell 14	Cell 15

16 Cell Block Learn Fuel Map

Today's Fuel Maps are far more complex, not only are there many sensors feeding the load calculation there are hundreds of cells that can be learned.

Fuel Injector
Pulse Width
(ms)

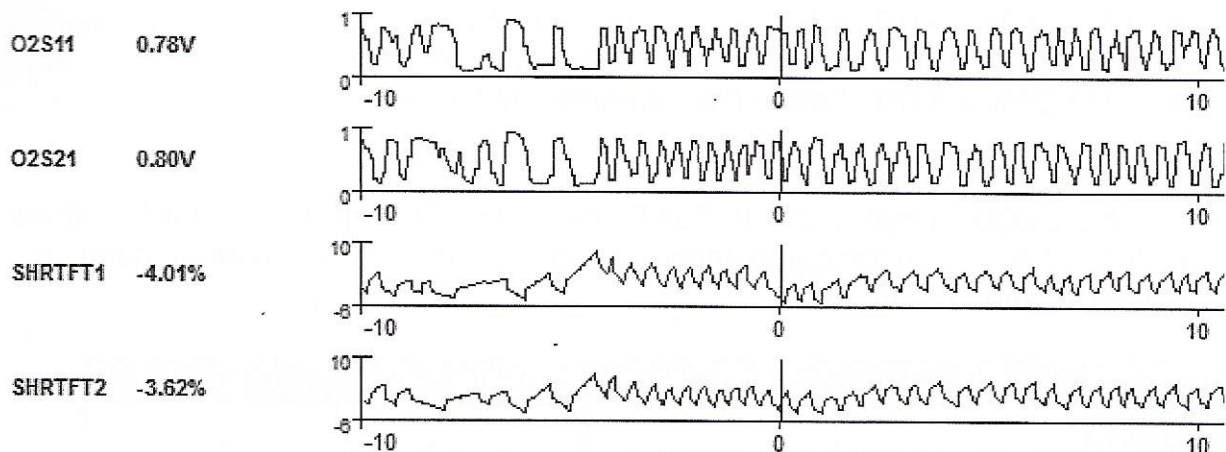


Example of a modern Fuel Map

READING FUEL TRIMS

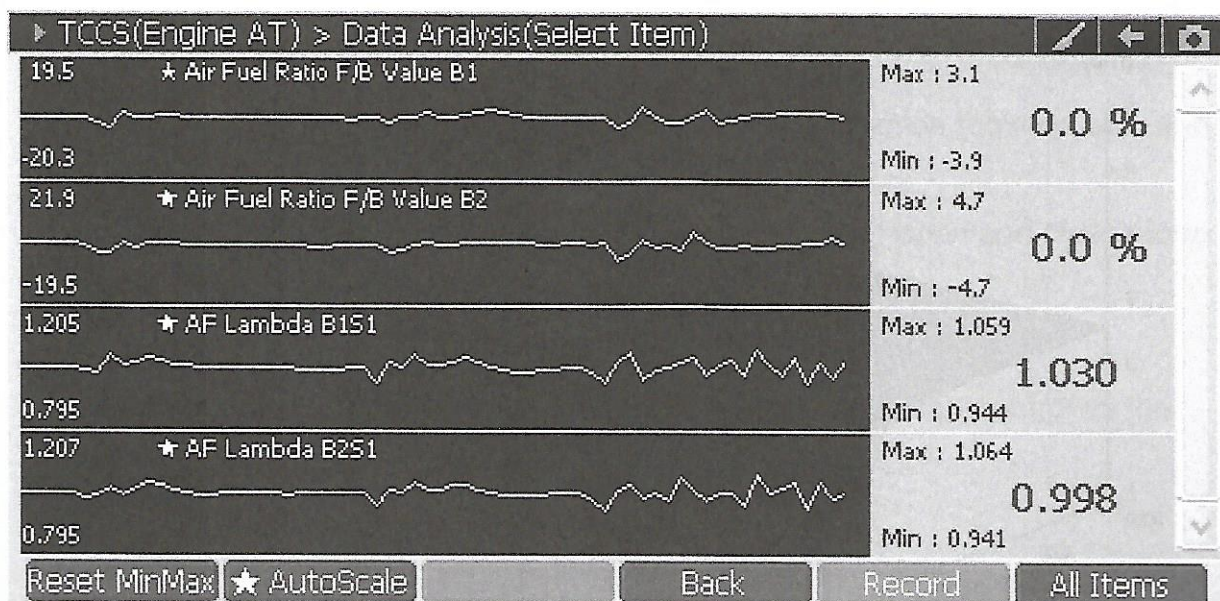
STFT

The short term fuel trims are driven directly by the UO2S. In older vehicles with Narrowband UO2S if the Scan Tool Data is graphed for the UO2S and the STFT alongside each other the switching of the UO2S between rich and lean is evident in the STFT.



In this graph of a known good Ford Escape V6 on a road test the connection between the two values is very clear. The first 10ms of the graph sees the vehicle load varying slightly and then stabilising in the last 10ms.

In 2018 we see a vast majority of Wideband UO2S's. As these sensors are far more accurate and do not rely on the 'switching' to control the STFT the connection between the two value is less obvious. But rest assured that the same relationship still exists..



In this graph of a known good Toyota Kluger V6 on a road test. The first two-thirds of the graph shows relatively stable driving, the last third had a lot of load variation and the capture ended with a closed throttle deceleration which caused the STFT to revert to 0.0%.

READING FUEL TRIMS continued...



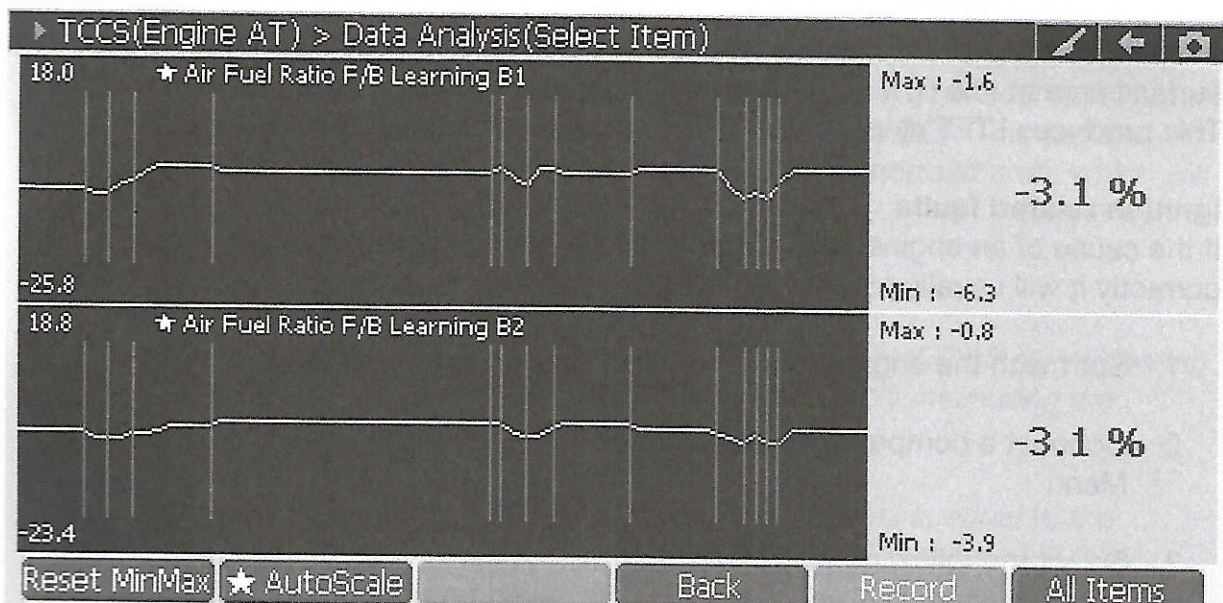
Note: STFT values of $\pm 5\%$ are considered normal as there will always be a delay in reaction as the exhaust sample has to travel from the combustion chamber to the UO₂S, where it is sampled and the signal is sent to the ECU. From there the injector pulse width is varied. By far the greatest delay is in the exhaust travel. For vehicles with Wideband UO₂S the normal parameters are $\pm 4\%$.



Caution: When road testing a vehicle for the purpose of using fuel trim for diagnosis try to limit driving that causes the ECU to switch into open loop.

LTFT

Long term fuel trims are learned from the STFT and taken from the average STFT value measured while operating in any particular calibration cell. This means that when you view the LTFT at idle you are only viewing the LTFT for the idle calibration cell. A short varied road test is required.



By viewing the LTFT during a varied road test it is possible to capture at least some of the switches between different cells. The vertical lines across this graph represent obvious switching of cells (it is likely that there are many other switches not captured by the Scan Tools slow response).

- * AFR sensor check for oscillations on STFT if so then sensor is functioning correctly.
- * Fuel Trim maps can be used when eng in open loop if a long term pattern is in place & not factory set map.

DIAGNOSTICS

Before starting on the diagnostics there is an old myth that needs to be debunked. It is often said that if a misfire is due to a lack of fuel the UO2S will register lean and a misfire due to a lack of ignition will register rich. This is completely untrue. As its name suggests, the UO2S only measures the oxygen content of the exhaust stream. Regardless of the cause of a misfire, excess oxygen will be measured at the UO2S and this will result positive STFT correction values. But that doesn't mean that the fuel trims are not useful...

LTFT Limits

There are two limits to consider with LTFT:

1. DTC fault trigger - Most vehicles will log P0171 to P0175 DTC's @ $\pm 25\%$
2. General understanding of normal limit - It is universally understood that a vehicle in good working order will not exceed $\pm 10\%$ LTFT.

Only Idle and low load fuel trims are high

Most likely an air leak on the Intake Manifold as the manifold vacuum is highest when the throttle opening is minimal. The unmetered air will register as lean at the UO2S, this will drive the fuel trims into the positive correction range.

Idle fuel trim negative, above idle positive

There is a phenomenon discussed in the second chapter of the Training Manual that describes how a contaminated MAF Sensor uses the contamination to increase its surface area at idle (low air volume) but acts as an insulator at higher air volumes. This produces LTFT at idle of $\pm -10\%$ and $>25\%$ at 80 to 100 km/h.

Ignition related faults

If the cause of an engine fault is due to a failure to ignite the air/fuel mixture correctly it will usually present as follows:

1. Start with the engine idling at normal operating temperature
2. Connect a compatible Scan Tool and navigate to the Scan Tool Data (PID) Menu
3. Select the following parameters
(where system is divided into 2 Banks select parameters for both banks):
 - UO2S
 - STFT
 - LTFT
 - DO2S
4. Drive the vehicle to the conditions that make the symptoms most evident
5. The UO2S will react giving a lean value:
 - a) Narrowband O2 = $<450\text{mV}$
 - b) Wideband O2 = $>1.01\lambda$ (λ = Lambda)

DIAGNOSTICS continued...

6. This will immediately result in a STFT positive correction, the correction will continue to compensate until the UO2S registers stoichiometric
 - a) Narrowband O2 = Switching
 - b) Wideband O2 = 1.00λ
7. Once the UO2S is registering stoichiometric, calculate the sum of the STFT and the LTFT - should be $<15\%$
(you will notice that the longer you watch these values the value of the LTFT will increase at the same rate that the STFT decreases, the net of the two values should be the same regardless)

**Note:**

When a misfire or an incomplete combustion event is caused by a lack of ignition, the air/fuel mixture enters the hot exhaust stream where some combustion occurs. The ECU will increase the pulse width of all cylinders on that bank until the equilibrium is achieved, for ignition faults this almost always occurs within 15% of the Primary Fuel Map!

8. To confirm that this truly is an ignition fault the presence of excess fuel will be evident in the catalytic converter. When unburnt fuel (hydrocarbons) enter the catalyst the oxygen is used to convert it into H_2O & CO_2 . This can be measured at the DO2S (to date virtually all DO2S are narrowband), which will produce a high voltage:
 - Intermittent faults $>650mV$
 - Single cylinder misfire $>900mV$

**Caution:**

Be careful not to think of the DO2S as monitoring lean or rich. They are simply measuring the presence of oxygen!

When oxygen in the exhaust is equal to the atmosphere the DO2S will generate $<100mV$

When there is no oxygen in the exhaust the DO2S will generate close to 1V

DIAGNOSTICS continued...

Lack of Fuel related faults

If the cause of an engine fault is due to a lack of fuel in the combustion chamber it will usually present as follows:

1. Start with the engine idling at normal operating temperature
 2. Connect a compatible Scan Tool and navigate to the Scan Tool Data (PID) Menu
 3. Select the following parameters
(where system is divided into 2 Banks select parameters for both banks):
 - UO2S
 - STFT
 - LTFT
 - DO2S
 4. Drive the vehicle to the conditions that make the symptoms most evident
 5. The UO2S will react giving a lean value
 - a) Narrowband O2 = <450mV
 - b) Wideband O2 = >1.01 λ (λ = Lambda)
 6. This will immediately result in a STFT positive correction
 7. Calculate the sum of the STFT and the LTFT - should be >15%
(you will notice that the longer you watch these values the value of the LTFT will increase at the same rate that the STFT decreases, the net of the two values should be the same regardless)
 - Intermittent faults >15%
 - Single cylinder misfire >40%
- 

Note: *When a misfire or an incomplete combustion event is caused by a lack of fuel, excess air enters the exhaust stream where some combustion occurs. The ECU will increase the pulse width of all cylinders on that bank until the equilibrium is achieved, for lack of fuel faults this almost always requires more than 15% extra fuel from the Primary Fuel Map!*
8. To confirm that this truly is a lack of fuel fault the presence of excess oxygen will be evident in the catalytic converter. Since the catalyst has excess oxygen it stores as much as possible and then lets the rest pass through to the DO2S, which will produce a low voltage:
 - Intermittent faults <350mV
 - Single cylinder misfire <100mV

Section vi**Alternative Combustion
Cycle Engines****CONTENTS**

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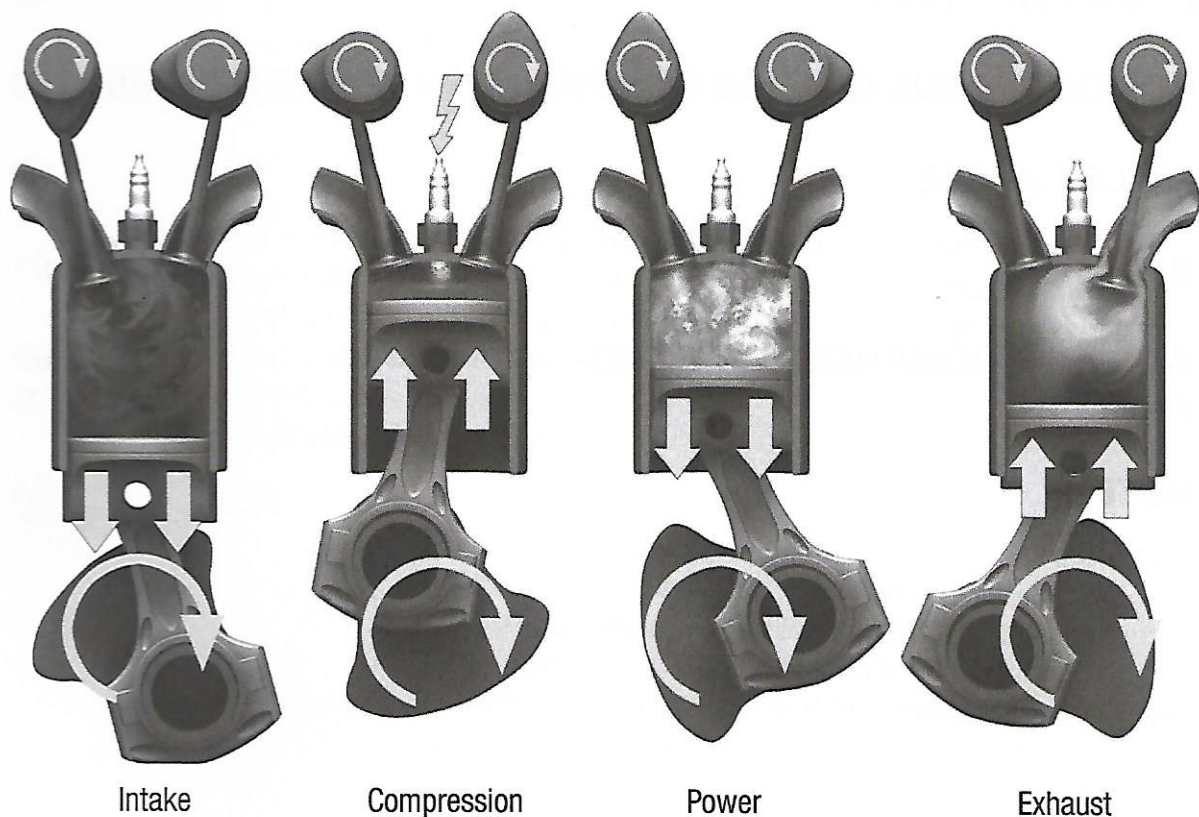
INTRODUCTION

The first Internal Combustion Engines (ICE) were modified steam engines. They were Two Stroke engines that would draw the intake charge in with the first half of the down stroke, ignition occurred in the second half of the down stroke (they did not compress the charge) and the upstroke was all exhaust. These early designs which were designed at the turn of the 18th Century proved to be extremely inefficient, but started the evolution of the ICE that continues until today.

There have been countless variations in both design and process of the ICE which have distilled down to just a handful of the most thermodynamically efficient designs. This topic will discuss the combustion cycles that have made it into the production line of modern vehicles, their benefits and their short-comings.

OTTO CYCLE

The Otto Cycle engine is the basis of all modern 4 Stroke engines and describes the relationship of the four strokes (Intake, Compression, Power and Exhaust) and their relationship to valve timing for greatest efficiency and power density.



DIESEL CYCLE

The Diesel Cycle engine conforms to the principles set out in the Otto Cycle with the variation of Compression Ignition.

ATKINSON CYCLE

The original design for the Atkinson Cycle employed a double-acting connecting rod with two crankshafts to create a variable stroke engine. The key feature of the Atkinson Cycle is that it extracts more energy out of the power stroke creating greater efficiency at the expense of power density. The Otto Cycle engine is the best compromise between efficiency and power however a lot of energy is wasted as heat out of the exhaust pipe, this is what the Atkinson Cycle addresses.

While technically speaking the modern Atkinson Cycle engine only simulates the Atkinson's Engine, the principles of combustion are faithful. The control of the camshaft phasers is used with the aim that at the bottom of the Power Stroke the pressure within the cylinder is equal to atmospheric pressure. It is by far the most commonly adopted alternative combustion cycle, so for the purpose of comparison the Toyota 1NZ engine is used, this engine is found in the Yaris (1NZ-FE) using the basic Otto Cycle and the Prius (1NZ-FXE) using the Atkinson Cycle.



Note:

It is worth noting that with wide ranging camshaft phasers Toyota and other manufacturers are producing engines that can switch between Otto and Atkinson Cycles!

Specification	Otto Cycle 1NZ-FE	Atkinson Cycle 1NZ-FXE
Bore & Stroke	75mm x 84.7mm	
Displacement	1497cm ³	
Compression Ratio	10.5:1	13.5:1
Torque	140Nm	110Nm
Power	82kW	52kW
Valve Timing	: IN Opening Angle : EX Opening Angle	

Simply put the main variation is the delay in closing the Inlet Valve which is around 60°. This equates to a reduction in the effective compression stroke of more than 50%.

Atkinson Cycle engines are used in almost all Hybrid vehicles as their losses in power density can be mitigated with the assistance of the electric motor/s.

MILLER CYCLE

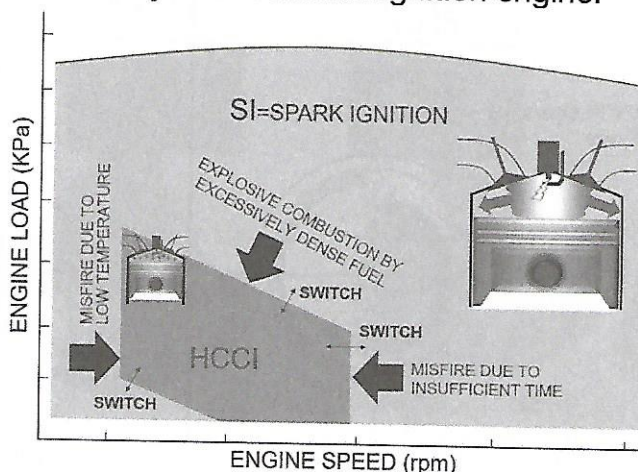
Ralph Miller cheated a little when he patented his engine in 1957, the Miller Cycle engine is simply an Atkinson Cycle that was applied to a conventional four stroke engine with a Supercharger to help overcome some of the power density losses. The major short coming of the Miller Cycle is that while the Supercharger improves the power losses it does it at the cost of efficiency due to the parasitic load of the Supercharger. With the additional build cost of the Supercharger it makes this and expensive technology with minimal gains.

The Miller Cycle engine was employed in the Eunos 800 (Mazda Millenia) between 1998-2002. It is also found on many modern 'down-sized engines' where a turbocharger is employed and is also integrated into other technologies.

HOMOGENEOUS CHARGE COMPRESSION IGNITION (HCCI)

Most manufacturers have been working on HCCI engine technologies for many years. In principle it is a port fuel injected petrol engine that uses compression ignition instead of a spark plug. HCCI produces the highest power from the least fuel with the fewest emissions of all known petrol combustion cycles. Unfortunately no one has yet been able to balance the variations in engine load with knock control.

Mazda claim to be releasing their new SkyActiv-X engine in the 2019MY Mazda3. While there are many references to HCCI it is in fact what Mazda call a Spark Plug Controlled Combustion Ignition (SPCCI). It will enter what Mazda claims to be HCCI mode under the perfect conditions, however the spark plugs are always fired. This means that it is not technically a combustion ignition engine.



Graphic illustrating the theoretical operation range of HCCI versus Spark Ignition (SI)

What is interesting about the SkyActiv-X engine is that it operates using the Atkinson and Miller Cycles by engaging and disengaging the Roots-type Supercharger:

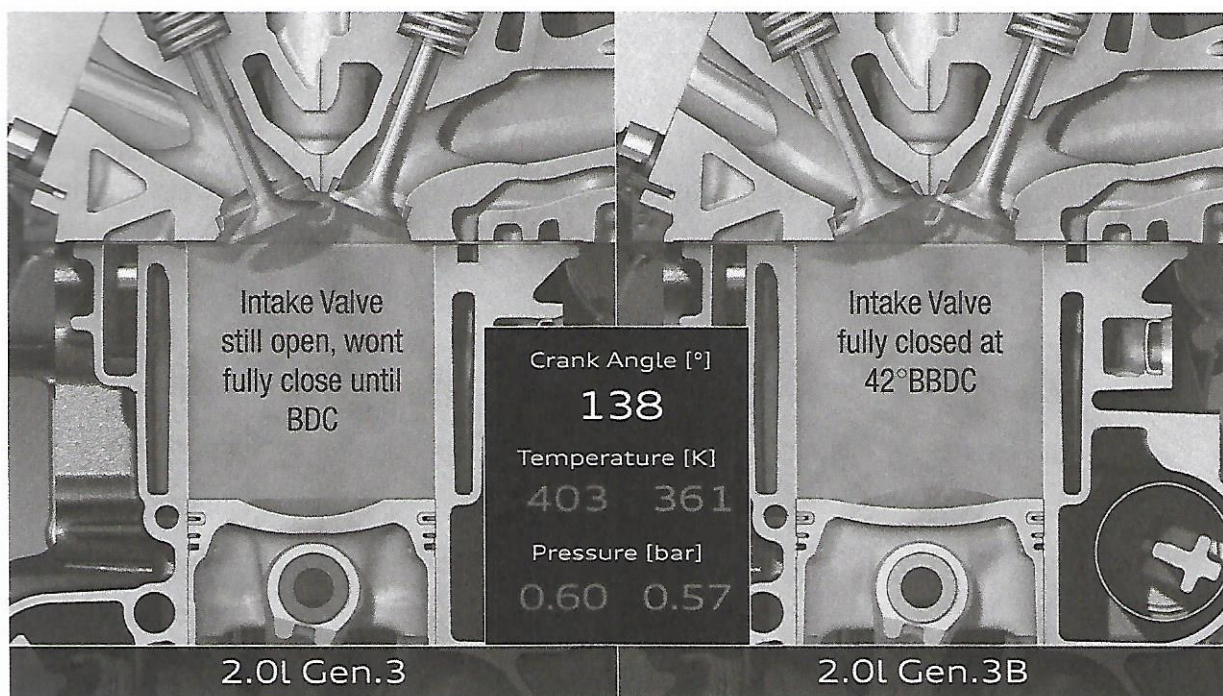
- Idle - Atkinson Cycle
- Low Load - SPCCI
- Partial Load - Atkinson Cycle
- High Load - Miller Cycle
- High Speed - Atkinson Cycle

B-CYCLE

The B-Cycle engine (named after VAG engineer Ralf Budack) was introduced in 2016 to Volkswagen Group (VAG) vehicles. It is an alteration of the EA888 engine now in its 3rd generation known as the Gen.3B, which uses the Audi Variable Valve Timing and Variable Valve Lift (AVS) technologies to create a variation of the Miller Cycle. The fitment of the engine can be identified by the engine code CVKB.

The one variation over Miller's design is that instead of closing the intake valves halfway up the compression stroke (70° to 115° ABDC), it closes the intake valves early (up to 70° BBDC). B-Cycle mode is active at idle through to partial load conditions. During B-Cycle mode:

- AVS switches to the low lift camshaft profile
- Throttle is always wide open
- Turbocharger boost pressure is increased up to 2.2bar
- Fuel is injected into the manifold (PFI) and the direct (DPI) injectors are not used



The B-Cycle engine was first used in the 2016MY Audi A4 and is used in the 2018MY VW Tiguan. There is currently no word from VAG as to when (or if) this engine will be introduced to Australia or New Zealand.

VARIABLE COMPRESSION RATIO

The Variable Compression Ratio (VCR) engine is another technology that has been attempted by numerous manufacturers (most notably GM, Mercedes Benz, SAAB and Peugeot) as a means of finding a compromise between efficiency and power density. Until now, none have made their way into full production due to high production cost (due to mechanical complexity) and minimal benefits.

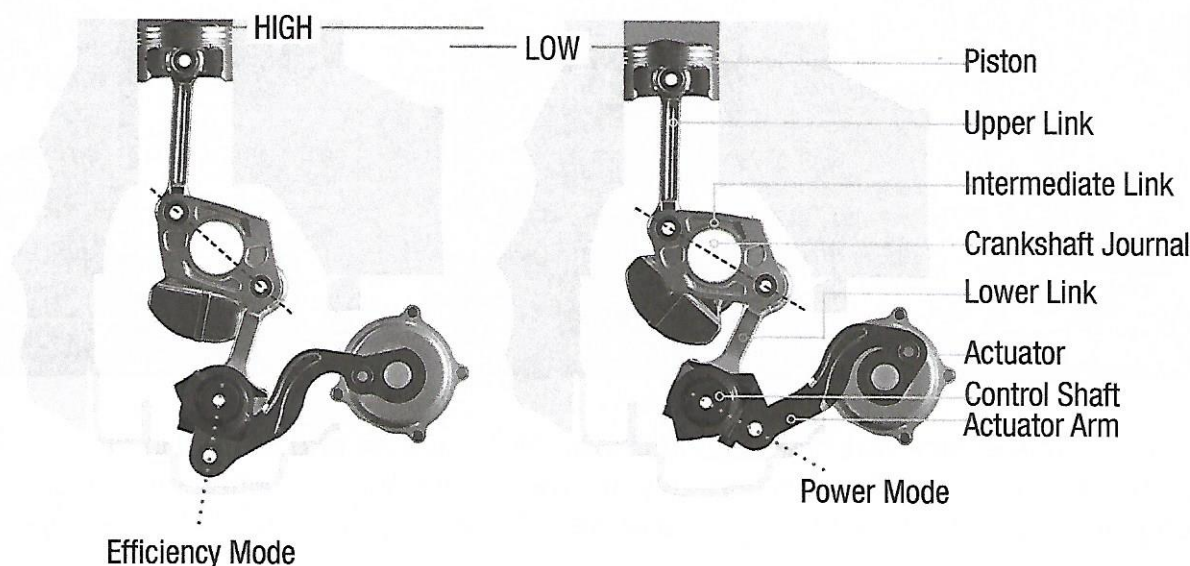
Infiniti VC-T

In the 2019MY Nissan's luxury marque Infiniti claims to be employing it's new KR20 VC-T (Variable Compression - Turbo) in the QX50. The engine is related to the MR20 that has been used by Nissan for many years. The key technologies employed by the VC-T engine include:

- Multi Link VCR System
- Turbocharger with wide operating range
- Electrically actuated inlet valve timing
- Hydraulically actuated exhaust valve timing
- Both PFI and DPI systems (Dual Injection)

Multi Link VCR System

The key feature is the complex Multi Link VCR System. As with all previous attempts at a production line VCR engine the Infiniti VC-T is mechanically complex and the downside of any mechanically complex system is production cost and in the case of the VC-T engine there are also additional weight and frictional losses.



Infiniti VC-T - Multi Link VCR System

In efficiency mode the compression ratio is cranked up to 14:1 and the turbocharger is wound back to minimal boost.

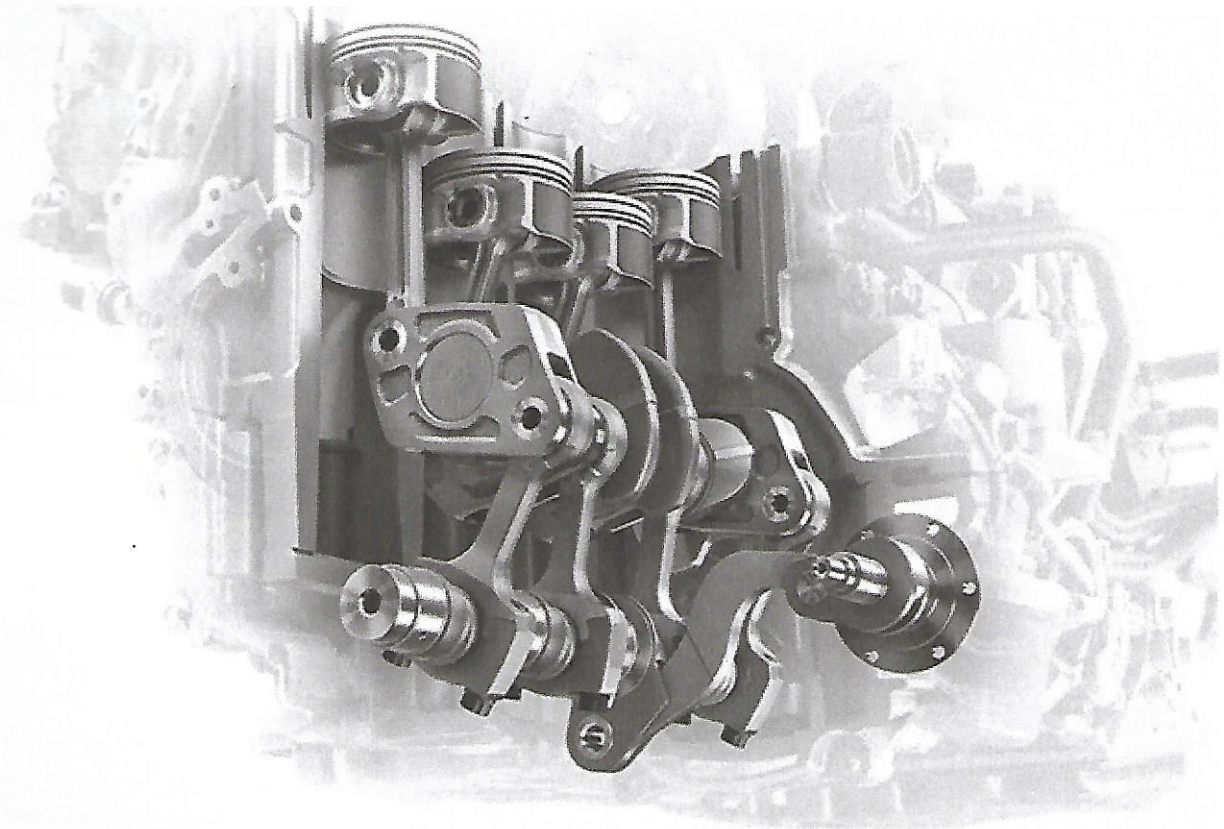
In power mode the compression ratio is eased back to 8:1 and the turbocharger is fully engaged to obtain the greatest possible charge.

VARIABLE COMPRESSION RATIO continued...

Infiniti employs the VCR system in collaboration with other efficiency saving technologies:

- Electronic VVT
- Dual Injection
- Variable displacement oil pump
- Atkinson Cycle Mode
- Miller Cycle Mode

Infiniti claims a 27% improvement over its outgoing naturally aspirated 3.5L V6, but with so many efficiency saving technologies it is impossible to separate which of these technologies is having the greatest impact.



3D cutaway of the Infiniti KR20 VC-T Engine

NOTES

Turn your Scan Tool into gas bench.

~~NOTE~~ USE Rear O₂ sensor Behind Cat.

mixture = unburnt fuel into cat which will use up
OR all the O₂ in Cat sending sensor up to
ENE Rich 0.9 volts Rich.

Lean = less unburnt fuel into cat which will increase
O₂ in Cat causing sensor to go down
to 0.1v lean.

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